for the maximum number of licenses the bidder intends to bid on in any round. An upfront payment of $1,050,000 gives a firm the ability to bid on three licenses—the maximum number a firm can win. An upfront payment of $3,500,000 gives the firm maximum bidding flexibility—the ability to bid on any number of licenses in any round.

2.4 Minimum Bid Increments

To assure that the auction concludes in a reasonable amount of time, the FCC specifies minimum bid increments between rounds. In the early rounds, a new bid must exceed the high bid from the prior round by 5% or the fixed amounts given in Table I, whichever is greater. Opening bids must exceed the minimum initial bid given in Table I.

The FCC reserved the right to adjust the bid increments in response to bidder behavior. In the early rounds, when bidder activity is high, the FCC is likely to set larger bid increments; in the later rounds, when bidder activity is low, the FCC is likely to set smaller bid increments.[9]

2.5 Activity Rule

The activity rule is a further device for controlling the pace of the auction. There are two stages. In the initial stage each bidder must be active on at least one license in every round. In the final stage, each bidder must be active on the maximum number of licenses he desires. The final stage begins by announcement any time after round 15. Each bidder is allowed five waivers of the activity rule. A waiver prevents a reduction in maximum eligibility in the prior round. Waivers are applied automatically. In stage one, if a bidder fails to bid in a round, then an automatic waiver is used to maintain the bidder's eligibility. In stage two, an automatic waiver is used whenever a bidder's eligibility would otherwise fall as a result of its reduced bid activity. A bidder that does not wish to maintain its eligibility from the prior round may override the automatic waiver.

2.6 Stopping Rule

A simultaneous stopping rule is used to give the bidders maximum flexibility in pursuing backup strategies. All markets close if a single round passes in which no new bids are submitted on any license.

9. The FCC established a panel of three experts to control the pace of the auction by setting the bid increment between rounds in addition to using other devices. The panel consisted of two economists, John McMillan and Charles Plott, and one professional auctioneer, William Stevenson.

TABLE I.
MINIMUM BID INCREMENTS AND MINIMUM INITIAL BIDS

License Number	License Type (kHz)	25% Credit for DE	Minimum Bid Increment	Minimum Initial Bid
1	50/50	No	$250,000	$500,000
2	50/50	No	$250,000	$500,000
3	50/50	No	$250,000	$500,000
4	50/50	No	$250,000	$500,000
5	50/50	Yes	$250,000	$500,000
6	50/12.5	No	$150,000	$300,000
7	50/12.5	No	$150,000	$300,000
8	50/12.5	Yes	$150,000	$300,000
10	50	No	$125,000	$250,000
11	50	Yes	$125,000	$250,000

Notes: DE – designated entity. License 9 not up for auction because awarded to Mtel as a Pioneer's Preference award.

Any time after round 20, the FCC may announce that the next or any future round is the last round of bidding. A "declared final round" is a last-ditch device that would only be used after other steps are taken to hasten the pace of the auction: shortening the time between rounds, extending the hours of the auction, increasing the bid increments, and moving to stage two. Automatic waivers do not keep the auction open. However, a bidder can submit a proactive waiver to keep the auction open. As a warning to bidders, the auctioneer will announce when the auction is about to close. For example, with ten minutes left, the auctioneer announces, "There have been no new bids or proactive waivers. The auction will close in ten minutes if no new bids are received."

2.7 Bid Information

Each bidder is given a confidential bidder number at registration. Results are displayed using the bidder number, rather than the bidder's name, to preserve privacy and limit opportunities for collusion or predatory bidding. High bids and bidder numbers are posted after each round. In addition, all valid bids and bidder numbers for each license are displayed at the conclusion of each bidding round.

2.8 Bid Withdrawal Penalty

To discourage insincere bidding, there are penalties for withdrawing a high bid. If a high bid is withdrawn before the auction closes, the penalty is the difference between the high bid and the eventual selling

price, unless the eventual selling price exceeds the withdrawn bid in which case the penalty is 0. If the bid is withdrawn after the close of the auction, there is an additional penalty of 3% of the minimum of the winning bid and the defaulting bid. After the close of each round, there is a ten-minute withdrawal period in which the prior high bidders can withdraw their bids. If a bidder withdraws its high bid, the bidder number for the withdrawn license is listed as "FCC," and the minimum bid is the prior high bid for that license.

2.9 Time Between Rounds

The length of a round is initially one hour with a withdrawal period of ten minutes. At this pace, given that five days were scheduled for bidding from 9 AM to 6 PM, the total number of rounds available is 30 (if one assumes the FCC needs 20 minutes to post results and instructions for each succeeding round). The number of rounds may be increased by extending the hours or shortening the time between rounds.

3. Bidder Preparation and Bidding Strategy

Bidder preparation began months, if not years, before the auction. The initial task was to develop plans for narrowband PCS applications. This task involves substantial research and development, both within the firm and in joint efforts with equipment vendors, to determine the technological and cost attributes of the services.[10] Marketing studies, including focus groups and demand analysis, are needed to assess demand for the services.

The next task that must be completed well in advance of the auction is acquiring the required capital. For most of the bidders, the auction prices are likely to be large relative to their liquid assets. Hence, the firms had to issue debt or sell equity. For example, "In January, [PageNet] began amassing a war chest with a $300 million debt offering to supplement a $100 million cash hoard and a $450 million line of credit." In the words of PageNet's President Terry L. Scott, "We came loaded for bear" (*Business Week*, August 15, 1994, p. 34). Budget constraints undoubtedly played a role in the bidding. The most successful firms raised sufficient funds so that the budget constraints would not get in the way.

10. A good example is the development of PageNet's VoiceNow service, which offers voice messaging with a device no bigger than a standard pager. The idea was initially conceived in-house, but then the voice pager was developed in a joint R&D venture with Motorola.

Meanwhile, the regulatory groups within the firms were busy lobbying the FCC in an effort to develop sensible auction rules that would respect their firms' interests. Most firms came before the FCC armed with an auction expert or two. In sharp contrast to the days of comparative hearings, the lobbying process was remarkably free of rent seeking. One of the great advantages of allocating the licenses by auction is that it removes most rent-seeking opportunities. Instead, the firms and the FCC focused on making the auction rules as efficient as possible.[11] Given the complexity of designing and implementing efficient auction procedures, the Commission chose to hire a leading game theorist (John McMillan) to advise it, and consulted extensively throughout the policy development and implementation process with outside experts.

The above tasks represented the backbone of the preparations. The next step was to develop a bidding strategy.

3.1 Valuation Model

The most important element in a bidding strategy is the valuation model. The better the information about values, the more successful the bidding is likely to be. In the nationwide narrowband auction, there are three types of licenses (50/50 kHz, 50/12.5 kHz, and 50 kHz). Each firm is eligible to hold up to three licenses in any geographic area. Hence, a complete valuation model should specify a value estimate for each possible auction outcome, that is, each combination of licenses. The valuation model should recognize that there are advantages to holding adjacent licenses. To reduce interference, adjacent licenses are separated with a "guard band" that cannot be used. However, if a single firm owns adjacent licenses, then it can use the guard band for transmissions, thereby making better use of the spectrum. This means that there is a premium to owning adjacent licenses. Since there are only two 50 kHz licenses and three 50/12.5 kHz licenses, there are a total of 36 possible outcomes, if one recognizes a premium for adjacency or the option of adjacency in the case of licenses that are adjacent to licenses that will be sold at a later narrowband auction. This is assuming that licenses of the same type are perfect substitutes ignoring the adjacency issue—a good assumption in the narrowband auction. Table II presents a table of the 36 different license combinations that need to be valued.

11. The auction experts played a central role in this debate. As a testament to the state of auction theory, the final rules represented a near consensus among auction experts. There was disagreement on a few issues such as the degree of simultaneity, but on most issues there was a consensus among the auction experts.

TABLE II.
POSSIBLE LICENSE COMBINATIONS TO BE VALUED RECOGNIZING VALUE OF ADJACENCY

	Number						Number				
Case	50/50s	50/12s	50s	No. adjacent	Adjacent Option	Case	50/50s	50/12s	50s	No. adjacent	Adjacent Option
1	3	0	0	2	0	19	2	0	0	0	0
2	3	0	0	1	0	20	1	1	0	0	1
3	3	0	0	0	0	21	1	1	0	0	0
4	2	1	0	1	0	22	1	0	1	0	1
5	2	1	0	0	0	23	1	0	1	0	0
6	2	0	1	1	0	24	0	2	0	1	1
7	2	0	1	0	0	25	0	2	0	1	0
8	1	2	0	1	0	26	0	2	0	0	1
9	1	2	0	0	0	27	0	1	1	0	1
10	1	1	1	0	0	28	0	1	1	0	0
11	1	0	2	1	0	29	0	0	2	1	1
12	0	3	0	2	0	30	1	0	0	0	1
13	0	2	1	1	0	31	1	0	0	0	0
14	0	2	1	0	0	32	0	1	0	0	1
15	0	1	2	1	0	33	0	1	0	0	0
16	2	0	0	1	1	34	0	0	1	0	1
17	2	0	0	1	0	35	0	0	1	0	0
18	2	0	0	0	1	36	0	0	0	0	0

Notes: No. adjacent = number of pairs of licenses that are adjacent. Adjacent option = case has fewer than three licenses and includes a license that is adjacent to a license that will be sold at a later auction.

The incremental value of spectrum typically declines with the number of licenses owned. For example, suppose that a single 50/50 kHz license has enough capacity to satisfy demand estimates over the next three years. The value of a second 50/50 kHz license is then reduced, because its capacity will be underutilized until several years after the award. However, if two 50/50 kHz licenses are essential in providing a viable service, then the value of the second 50/50 kHz license may well exceed the value of the first.

In determining values, it is important not only to make point estimates of value but to gauge the extent and source of uncertainty in the estimates. This is an essential input in determining the bidding discount factor described in the next subsection.

The valuation estimates should reflect the fact that there are alternatives to winning in the nationwide auction. The most obvious alternatives are the regional, major trading area (MTA), and basic trading area (BTA) auctions.[12] Indeed, only a minority of all narrowband spectrum is auctioned on a nationwide basis, as can be seen in Table III.

12. Each BTA is a collection of counties, each MTA is a collection of BTAs, and each region is a collection of MTAs. In the United States, there are 3,142 counties, 493 BTAs, 51 MTAs, and 5 regions.

TABLE III.
SUPPLY OF NARROWBAND PCS SPECTRUM BY AUCTION

	Number of Licenses in Area				Response Channel	
License Type	Nationwide	Regional	MTA	BTA	MTA	BTA
50/50 kHz	5	2	2			
50/12.5 kHz	3	4	3	2		
50 kHz (outbound)	2		2			
12.5 kHz (inbound)					4	4
Number per area	10	6	7	2	4	4
Number of areas	1	5	51	493	51	493
Outbound (kHz)	500	300	350	100		
Inbound (kHz)	287.5	150	137.5	25	50	50
Total (kHz)	787.5	450	487.5	125	50	50
Outbound (%)	40.0	24.0	28.0	8.0		
Inbound (%)	41.1	21.4	19.6	3.6	7.1	7.1
Total (%)	40.4	23.1	25.0	6.4	2.6	2.6

Notes: MTA = Metropolitan Trading Area; BTA = Basic Trading Area; MTAs and BTAs are based on the *Rand McNally 1992 Commercial Atlas and Marketing Guide*, 123rd Edition, pp. 38–39.

A nationwide aggregation of regional, MTA, or BTA licenses is roughly equivalent to a nationwide license of the same type. Bidders must assess the demand for regional, MTA, and BTA licenses in determining values for the nationwide auction. If the bidder anticipates that the demand for regional and MTA licenses is likely to be quite strong, then it may be that the option of waiting for the regional or MTA auctions is of little value. However, if there is a reasonable possibility that the demand for regional or MTA licenses is weak, then the bidder may wish to reduce the valuations because of the regional or MTA option. Some information about regional or MTA demand may be revealed during the nationwide auction. For example, if bidders observe one or more firms known to have a nationwide strategy drop out of the nationwide auction, then it may be that they are switching to a regional or MTA backup strategy, which will increase the demand (and prices) in these auctions.

The regional, MTA, and BTA licenses may also be used to supplement nationwide licenses. For example, suppose a single nationwide 50/50 kHz offers enough capacity in most MTAs. Then the bidder could bid on only those MTAs where it has a shortage of capacity. Of course, these are likely to be the most sought after MTAs. Also, for some applications it may not be technically feasible to use an MTA specific channel to supplement a nationwide service.

The response channel licenses are another alternative to a nationwide license. When used with a bidder's existing licenses, a nation-

wide aggregation of response channel licenses would be equivalent to a nationwide 50/12.5 kHz license. Because only incumbent firms are eligible for response channels, competition in the response channel auction may be more limited, and prices may be low. However, under the proposed rules for the response channel auction, it will be nearly impossible to acquire a nationwide aggregation at auction.[13] The aggregation becomes even more unlikely if it is necessary to have the same channel across MTAs or BTAs. Finally, most incumbent bidders are not eligible to bid on all MTAs (a problem that may be resolved by subsequent FCC action). Unless the rules are changed, the response channels would have to be viewed as a supplement to a nationwide service and not as a means of forming a nationwide aggregation.

The final option is acquiring needed spectrum through postauction trade or acquisition. This option may prove attractive if the bidding gets overheated, especially if some of the high bidders appear to be in a poor position to utilize the spectrum they acquire in the auction. It may be better to purchase additional licenses after the auction. It is not uncommon for postauction prices to be below auction prices. A recent example is wine auctions in France. Throughout the 1980s, wine futures have sold at a substantial premium at wine auctions (Ashenfelter, 1989). However, since postauction purchase of spectrum may involve considerable delay, this is a better strategy for additional capacity, not essential capacity. The essential capacity for a nationwide service most likely should be acquired in the nationwide auction.

Although estimating sales prices in the regional, MTA, BTA, and postauction markets is an uncertain business, it nonetheless is important to include these options in the analysis.

Despite all this complexity, it is important that the valuation model be simple enough to be understood easily by top management. In the final analysis, valuations will be set by top management. Hence, it is important that the valuation model not only be understandable by managers, but also be flexible enough to incorporate their judgments. Otherwise, the model will be cast aside in favor of intuition and rules of thumb.

In what follows, I sketch a simple and yet flexible valuation model. This valuation model is the basis of the simulation discussed

13. However, the FCC has decided to rethink the rules for the response channel auction as soon as more experience is gained with the simultaneous multiple-round auction. The FCC's preliminary rules were made in great haste under the assumption that the response channel licenses would have a low value—an assumption that appears false if one judges from the prices in the nationwide auction.

in the next section. The valuation model depends on three essential parameters:

- r = ratio of the value of inbound spectrum to outbound spectrum
- α = the extent of diminishing returns for inbound spectrum
- β = the extent of diminishing returns for outbound spectrum

It is assumed that values can be stated in terms of the value of the best possible outcome (case 1: three adjacent 50/50 kHz licenses). Specifically, the value of any license combination as a fraction of the value of the best outcome is:

$$V_i = \frac{T_i}{\max_j T_j}$$

where

$$T_i = r \cdot A_i^{\alpha} + B_i^{\beta},$$

and A_i is the fraction of inbound spectrum in case i relative to case 1, and B_i is the fraction of outbound spectrum in case i relative to case 1, by recognizing a premium for adjacency. Table IV gives a sample value table by assuming an adjacency premium of 5% and a premium for the option of adjacency of 2.5%. The premium associated with an option of adjacency is reduced by the probability that the firm will be successful in acquiring the adjacent band in the subsequent auction.

3.2 Bidding Discount

A natural bidding strategy would be to estimate values for the various license combinations, bid on the licenses that represent the best values, and then stop bidding when the high bids exceed your value estimates. Unfortunately, bidding strategy is not so intuitive. In most auction environments, this strategy leads to the *winner's curse:* The winner of the auction ends up paying more than what the item is worth.

To see why this happens consider the following situation: Suppose I am auctioning off a jar of quarters. You are one of 24 bidders in the room. Each bidder looks at the jar, estimates the number of quarters, and then bids up to this estimated value. Suppose that each estimate is unbiased in the sense that the expected value of the jar is equal to the estimate—some estimates are low, some are high, but the average is about right. Now suppose that you find that you have won the auction. Should you feel glad that you were able to acquire

TABLE IV.
VALUE FOR EACH LICENSE COMBINATION (R = 1.35, α = 0.85, β = 0.8)

Case i	Number 50/50 Licenses	Number 50/12 Licenses	Number 50 Licenses	No. Adjacent	Adjacent Option	Inbound Spectrum A_i (kHz)	Outbound Spectrum B_i (kHz)	Value Relative to Case 1 V_i (%)
1	3	0	0	2	0	160	160	100
2	3	0	0	1	0	155	155	97
3	3	0	0	0	0	150	150	95
4	2	1	0	1	0	118	155	86
5	2	1	0	0	0	113	150	83
6	2	0	1	1	0	105	155	82
7	2	0	1	0	0	100	150	79
8	1	2	0	1	0	76	155	72
9	1	2	0	0	0	75	150	71
10	1	1	1	0	0	63	150	66
11	1	0	2	1	0	50	155	63
12	0	3	0	2	0	40	160	60
13	0	2	1	1	0	26	155	54
14	0	2	1	0	0	25	150	52
15	0	1	2	1	0	13	155	48
16	2	0	0	1	1	105	106	71
17	2	0	0	1	0	105	105	71
18	2	0	0	0	1	101	101	68
19	2	0	0	0	0	100	100	68
20	1	1	0	0	1	63	101	55
21	1	1	0	0	0	63	100	55
22	1	0	1	0	1	50	101	51
23	1	0	1	0	0	50	100	51
24	0	2	0	1	1	26	106	43
25	0	2	0	1	0	26	105	43
26	0	2	0	0	1	25	101	41
27	0	1	1	0	1	13	101	36
28	0	1	1	0	0	13	100	36
29	0	0	2	1	1	0	106	31
30	1	0	0	0	1	51	51	39
31	1	0	0	0	0	50	50	38
32	0	1	0	0	1	13	51	24
33	0	1	0	0	0	13	50	23
34	0	0	1	0	1	0	51	17
35	0	0	1	0	0	0	50	17
36	0	0	0	0	0	0	0	0

Notes: No. adjacent = number of pairs of licenses that are adjacent; adjacent option = case has less than three licenses and includes a license that is adjacent to a license that will be sold at a later auction. I have chosen the parameter values r, α, and β to fit the auction outcome; they are *not* the values used by PageNet.

the quarters for less than your estimate? No—at least not upon reflection. You won the auction because you had the highest estimate among the 24 bidders. Winning means that you *overestimated* the value the most. Although your estimate is initially unbiased, when you find that you won the auction your estimate *is* biased. The true value, in all likelihood, is substantially less than your estimate.

The winner's curse is commonly observed.[14] I have conducted the jar of quarters experiment dozens of times with students and business executives. Every time, I make money. Usually $8 in quarters sells for between $10 and $20. During a demonstration of the simultaneous multiple-round auction in January 1994,[15] winning bidders lost hundreds of fictitious dollars bidding on licenses worth hundreds of dollars. The bidders were FCC staff and representatives from several telecommunications companies.

Sophisticated bidders avoid the winner's curse by discounting the value estimates to reflect the negative information that winning conveys. The fact that you won means that no one else was willing to pay as much. The relevant estimate is the value *conditional on winning*, that is, the expected value conditional on the fact that your estimate is the highest of the 24 estimates. You can safely bid up to this conditional value without fear of losing money.

In understanding the winner's curse, it is helpful to think of two extreme types of auctions: a common value auction and a private value auction. The jar of quarters example is stark in that it is a pure *common value* auction. The item being auctioned is worth the same to everyone, and each bidder makes independent estimates of this uncertain value. The winner's curse is greatest in this extreme case. At the other extreme is a *private value* auction in which the item is worth different amounts to each bidder, and each bidder *knows* what it is worth to him, but not what it is worth to the others. In a pure private values auction, the strategy of bidding up to your private value is the best strategy. The winner's curse is not an issue, because winning does not convey any negative information about value. Winning simply means that the item is worth more to you than to the others.

Bidding on oil leases is a common value auction. The oil is worth the same to all bidders. Each bidder makes an estimate of this value, but no one knows what the true value is. It depends on how much oil is in the ground, how costly it is to extract, the future price of oil, etc. An example of a private value auction would be an art auction,

14. The winner's curse was originally studied in Wilson (1969) and then Ortega-Reichert (1968) and Rothkopf (1969). See Capen et al. (1971) for a discussion of the winner's curve in bidding for oil leases and Hendricks et al. (1987) for empirical evidence. For experimental evidence on the winner's curse, see Bazerman and Samuelson (1983), Dyer et al. (1989), Giliberto and Varaiya (1989), Kagel and Levin (1986), Kagel et al. (1987, 1989), Levin et al. (1994), Thaler (1988), and Thiel (1988).

15. The demonstration was part of a conference, "Spectrum Allocation: Auction Designs and Their Potential Impacts" at the Annenberg Washington Program in Washington, DC, organized by Barry Nalebuff and sponsored by the Sloan Foundation and the Yale School of Organization and Management.

where the art is purchased for private consumption rather than resale. A bidder's value of the art depends solely on the bidder's particular preferences.

The broadband PCS auction is a hybrid of these two auction forms. There are both private value and common value components. Some bidding discount is necessary, but the discount is not as large as in a pure common value auction. The discount depends on the extent of common value uncertainty. The key question is, To what extend do firms' value estimates differ because firms make different assumptions about factors that affect the value of the licenses to all bidders?

3.2.1 Sources of Common Value Uncertainty. There are several potential sources for common value uncertainty. All relate either to the cost of alternative sources of spectrum or to the profitability of future narrowband PCS markets.

- The FCC has reserved a third megahertz of narrowband PCS spectrum for future use. When will the FCC auction the third megahertz? Who will be eligible to bid?
- What will the sale prices be in the regional, MTA, BTA, response channel, and postauction markets?
- How competitive will the narrowband PCS markets be? What rates will the market support? How fast will costs decline with technological improvements?
- How fast will the narrowband PCS market grow? What market share will the firm be able to sustain?

The answer to each of these questions will affect estimates of value to all bidders. To the extent that firms draw different conclusions, estimates of common value will differ. These potential differences imply that winning will convey negative information. Value estimates should be discounted to avoid the winner's curse.

3.2.2 Setting the Discount. Determining an appropriate bid discount is part art and part science. First, the science: In an ascending-bid auction, the optimal bidding rule is to bid up to the estimate of value conditional on winning. In a common value auction, this conditional valuation can be determined once a distribution of uncertainty is specified.

Suppose there are n bidders ($i = 1, \ldots, n$), and each bidder has an estimate $x_i = v + \epsilon_i$, where v is the true value and ϵ_i (the error in the estimate) is normally distributed with mean 0 and standard deviation σ. This means that each bidder's estimate is unbiased (since the mean error is 0). However, the maximum of the n estimates is

TABLE V.

Normal and Lognormal Bias Factors in Symmetric Common Value Auction

Form of Uncertainty	Number of Bidders 2	4	8	16	32
Normal	.56	1.03	1.42	1.77	2.07
Lognormal with $\sigma = .5$	1.27	1.57	1.89	2.22	2.56
Lognormal with $\sigma = 1$	1.52	2.21	3.08	4.17	5.48

Notes: Both models assume that the marginal distribution of the common value has an infinite variance, σ is the standard deviation of the conditional distribution of the log of the value in the lognormal model. With normal uncertainty, the bias factor is the number of standard deviations of bias (e.g., with two bidders, the highest estimate is biased by .56 standard deviations; with lognormal uncertainty, the bias factor is the factor by which the highest estimate is biased (e.g., with two bidders and $\sigma = .5$ the highest estimate would be unbiased if it was discounted by 1/1.27). *Source:* Wilson (1992a, p. 25).

biased according to the normal bias factors in Table V. For example, with 16 bidders and a standard deviation of $10 million, the maximum of the 16 estimates is biased by $17.7 million. Therefore, each bidder should reduce its estimate of value by $17.7 million. The size of the reduction depends on the number of bidders and the amount of uncertainty. This is true in general. A larger discount is needed the more uncertainty there is and the greater the number of bidders.

Alternatively, suppose that the estimates have an unbiased lognormal distribution, as is the case in the oil industry.[16] Then, winning among n bidders tells you that the estimate is biased by the lognormal bias factors in Table V. For example, with $\sigma = .5$ (this means that the log of the estimates has a standard deviation of .5) and 16 bidders, then the maximum of the 16 estimates is biased by a factor of 2.22. Therefore, a bidder with an unconditional estimate of $20 million should stop bidding when the bidding reaches 20/2.22 = $9 million.

An important difference between the above settings and the nationwide auction is that in the nationwide auction, there are several equivalent items for sale. Suppose that there are 20 bidders, 10 equivalent items for sale, and each bidder has a demand for one item. In this case, the bidders will want to condition their valuation on the fact that they have the *tenth* highest of the 20 estimates. But the tenth highest estimate is unbiased. No correction is needed! In the nationwide auction, the number of bidders will be revealed before the auction, but the number of licenses each firm demands will range from one to three and will not be known. In this setting, it is not straightfor-

16. Lognormal uncertainty arises when the estimate is the *product* of a number of independent random events.

ward to determine how much estimates should be discounted to avoid the winner's curse. However, the bias factors in Table V greatly *overstate* the bias of the estimate of a winning bidder in the nationwide PCS auction. A practical approach to determine the bias in estimates is to keep track of bidder activity. The sooner bidders drop out and the greater the number that drop out, the more biased is the estimate.

A second important difference between the settings above and the nationwide auction is that the bidders are not identical. Each firm has particular capabilities and has different plans for using the spectrum. If bidders drop out of the auction because of differences in private values, then nothing is learned from their exit. The bidding discount must be reduced to the extent that differences in private values are important. Private values depend on the unique attributes of the firms. Ideally, each firm should determine its competitive advantage (costs, technology, marketing, etc.) and those of its competitors. When a competitor drops out of the auction, the firm should ask, Why? Was its estimate of value low because of a low private value or a low estimate of common value? Unfortunately, answering this question is difficult since bidder identities are not revealed. The bidders know that someone dropped out, but they do not know who.

One way to get a rough idea of how biased winning estimates are is to simulate the nationwide narrowband auction. This approach is discussed later in this section.

3.3 Which Licenses To Bid On?

An obvious strategy is simply to bid on the set of licenses that represents the best value given the current prices. Indeed, this is probably the best strategy much of the time. However, several complications need to be addressed. The first stems from the fact that bidders can acquire multiple licenses. As a result, a bidder must recognize that its demand for an additional license will raise prices. For example, a bidder that prefers two 50/50 kHz licenses to one 50/50 kHz and one 50 kHz license at the current prices may be better off dropping down to one 50/50 and one 50, because holding out for two 50/50s will raise the price on all 50/50s. Hence, the decisions about what to go for and when to drop down to less desirable licenses are complex. The correct action requires a good sense of the demand for the various types of licenses.

A second complication related to the first is signaling. Since decisions of when to drop down depend on one's beliefs about demand, bidders may attempt to influence those beliefs through their bidding.

A bidder can signal a high value, thereby warning rivals to look elsewhere, by jump bidding—bidding well in excess of the minimum bid.

Another form of jump bidding is bidding on more licenses than one is eligible to win (i.e., more than three). Doing so exposes the bidder to substantial bidding penalties if the bids turn out to be winners. However, if the bids are placed at a time when bidding activity is still strong, then the move can signal strength and hasten the auction along.

It is important to be cognizant of the activity rules when one is deciding on which licenses to bid. During the first stage of the auction, each bidder must be "active" in every round. A bidder is active if it is the current high bidder or it submits at least one bid in the round. In the first stage, activity on a single license is sufficient to maintain full eligibility. Hence, it is possible in stage one to "hide in the grass," bidding the minimum bid on the cheapest license. In the final stage (to be announced by the FCC after round 15), a bidder must remain active on the number of licenses it wishes to remain eligible for. A bidder active on only a single license would only be eligible to bid on one license in future rounds. Stage two, then, forces a strong bidder desiring multiple licenses to come out of the grass. However, each bidder has five waivers to the activity rules, so that withdrawals can be faked at little cost. (This is one of the costs of allowing waivers and concealing their use: The bidders get less accurate information about when others drop out, which aggravates the winner's curse.) A waiver must be used in any round in which the activity rule it not satisfied to prevent a reduction in eligibility.

Satisfying the activity rules is not a problem in the first stage. The bidder always has the option of bidding the minimum bid on the most underpriced license. In the final stage, satisfying the activity rule can be an issue. For example, in a particular round the most profitable bid may be for a single 50/50 kHz license, with a pair of 50/12.5 kHz licenses being the second most profitable set of licenses on which to bid. In subsequent rounds, the price of the 50/50s may increase to the point where the pair of 50/12.5s is more desirable. Under the final-stage rules, eligibility for the pair of 50/12.5s would be lost. I view a situation like this as unlikely. Typically, bidders will want to reduce activity as prices rise, rather than the reverse. Moreover, a bidder can determine at any point in the bidding whether there is a possibility that the bidder will want to increase its activity in later rounds. In this case (which is unlikely), the opportunity cost of reducing its activity must be included in the decision to bid on fewer licenses. The availability of waivers plays a role in determining this oppor-

tunity cost. If all five waivers are available, then the opportunity cost may be low; if only a single waiver is available, then the opportunity cost may be substantial. In my mind, this is one of the main uses of waivers.

3.4 Simulation of the Auction

To better understand these strategy issues and the implications of various auction rules, I constructed a simulation of the nationwide narrowband auction. By conducting thousands of computer simulations, one is able to get an empirical sense for how the auction rules affect the auction outcome. From the FCC's point of view, it is especially important to understand how to control the pace of the auction so that the auction concludes in a timely fashion. Simulations are also useful in testing and improving bidding strategies. Although existing auction theory is enormously helpful in understanding issues of auction design and bidding strategy, the spectrum auctions are too complex for the theory to offer definitive answers. The theory needs to be supplemented with analysis from auction simulations as well as judgment.

The simulation is based on the valuation model described earlier. However, for the simulation it is necessary to introduce uncertainty. I use a simple yet widely applicable model that is a hybrid of common and private value models.[17] The model has five sources of uncertainty. The first is the common value factor f_c, which is normally distributed with mean one. Each firm observes an independent estimate $e = \nu \cdot f_c$ of the common value ν, the average industry value of three adjacent 50/50 kHz licenses (case 1). Since f_c has a mean of one, the estimates are unbiased. The next source of uncertainty is the private factor f_p, which also is normally distributed with a mean of one. This independent factor determines a firm's value of three adjacent 50/50 kHz licenses (case 1). The firm's estimated value of case 1 is $\nu \cdot f_c \cdot f_p$, and the true value is $\nu \cdot f_p$. The estimated value of all other cases is a fraction of the case 1 value, where the fraction is determined from the function $V_i(r, \alpha, \beta)$, as described earlier. Each of the variables, r, α, and β is an independent firm-specific normal random variable with mean and standard deviation given in Table VI. To get an empirical sense of how the bargaining outcome depends on the various parameters, it is necessary to vary the parameters across simulations. In any simulation, these parameters are the same for all firms and are common knowledge. For each simulation, the parameters are drawn from independent uniform distributions with lower and upper bounds given in Table VI. These distributions are roughly consistent with the outcome of the actual auction. The number of bidders n is chosen so that all integers from 10 to 20 are equally likely. n should be viewed as the number of *serious* bidders—bidders that have a reasonable chance of winning one or more licenses.

17. Wilson (1981, 1992b) analyzes a related model in which the value estimate is the product of a common and private factor.

TABLE VI.
VALUE ESTIMATE OF LICENSE COMBINATION $I = \nu_I = \nu \cdot f_c f_p \cdot V_I(r,\alpha,\beta)$

Sources of Uncertainty Within Simulation (independent normal distributions)			Sources of Variation Across Simulations (independent uniform distributions)		
Variable	Mean	Standard Deviation	Parameter	Lower Bound	Upper Bound
Common value factor, f_c	1	σ_c	σ_c	.1	.3
Private value factor, f_p	1	σ_p	σ_p	.1	.3
Inbound to outbound value, r	μ_r	σ_r	μ_r	1	1.7
Returns to inbound spectrum, α	μ_α	σ_α	μ_α	.75	.95
Returns to outbound spectrum, β	μ_β	σ_β	μ_β	.7	.9
			Common value ($M), ν	150	250

Notes: The common value ν is the average industry value of case 1 (three adjacent 50/50 kHz licenses). The parameters σ_r, σ_α, and σ_β all equal .2; they do not vary across simulations.

The final element of the simulation is the bidding. In this preliminary simulation, I ignore issues of signaling, asymmetric bidders, and strategic issues of acquiring multiple licenses. Instead, I assume that bidders adopt a conservative and sincere strategy. In any round, the bidders place bids on the licenses that represent the best value given the current high bids and their valuation estimates. The bid on any license is equal to the minimum bid plus a small random term. The random term avoids ties. More importantly, the random term reduces the chance that all the bids for a particular license type will fall on the cheapest license, when the differences in prices are small. Each random term is drawn independently from a uniform distribution on $[0, h]$. For each simulation, the parameter h is drawn from the uniform distribution from \$1k to \$1M.

The bidders continue to bid so long as prices are below values.

This strategy mimics the symmetric equilibrium in a standard English auction. The bids maximize the firm's profit given the current information, if one *assumes these bids turn out to be winning bids*. In calculating profit, the bidders adjust their valuation estimates to reflect any negative information conveyed by winning.

3.5 How Biased Are Winning Estimates?

For the above bidding strategy to be an equilibrium, the bidders must correctly discount their estimates to avoid the winner's curse. I calculate the bias of winning estimates using an iterative process. I begin by "guessing" that the winning bias is σ_c, so that bidders discount their estimates by the factor $1/(1 + \sigma_c)$. I then run 1,000 simulations and estimate the bias as a function of the model parameters, using linear regression. I then run 1,000 more simulations, discounting value estimates according to the estimate of bias from the regression. These simulations are then used to re-estimate the bias. I continue this process until the regression coefficients have converged. The stable model of bias is then used to determine the bidding discount in all subsequent simulations.

Based on the simulations, I estimate the bias to depend on the model parameters as follows:[18]

$$\text{Bias} = .002n + .78\sigma_c - .13\sigma_p - .05.$$

The simulation confirms that the bias of the winning estimates is largely a function of the amount of common value uncertainty. Bias increases with the number of bidders and decreases with private value uncertainty. Hence, if there are 20 bidders and the common and private value factors have standard deviations of 20%, then I would estimate the bias to be 12%. In this setting, sometimes the bias is greater than 12% and sometimes it is less than 12%, but on average the bias of the winning estimates is 12%.

The bias of an estimate is also likely to depend on the size of one's private value factor. If one has a small private value factor for a license and yet still wins, it is more likely that the estimate of common value is biased. Similarly, if one's private value factor is large, one's estimate of common value is probably less biased. Thus far, I have not included a bidder's private value factor in the estimate of bias.

18. Given the multiplicative valuation model, I also estimated bias with a log-linear model. Both models explain about a third of the variance. Including other parameters, such as μ_r, μ_α, and μ_β, add little.

3.6 Mock Auctions

Conducting mock auctions is essential to developing a good bidding strategy. It is the best way for top management to become familiar with the auction process and test strategy ideas. Every time I run a mock auction new insights come to light—insights that would not be discovered by simply thinking or brainstorming about strategy. Most of the large bidders conducted some form of mock auction as part of their preparations. In my work for PageNet, I created and ran two mock auctions. In the first, the bidders were given a value table and instructed to bid so as to maximize their profit. In the second mock auction, each bidder was given a value table as well as a computer that ran the bidding model. In this way, every member of the bidding team had experience with the bidding model. In each round, the model would suggest a bidding strategy given the bidders' valuations and the current prices. The bidders then used this information as a guide in deciding how to bid. There was not a problem with the bidders blindly following the advice of the computer. Experimentation was common.

The simulation was useful in running the mock auctions. We anticipated that there would be about twenty serious bidders in the real auction. Since we did not have twenty people on the bidding team, we ran the mock auctions with five real bidders and 15 computer simulated bidders. This combination of real and simulated bidders worked very well.

4. Bidding Behavior

"A collective gasp swept the ballroom as the first round of results was announced: Bidding had started at $20 million each for two licenses and $10 million for five others." (*Washington Post*, July 26, 1994, p. D1.) With the FCC's minimum initial bid set at $250,000 to $500,000, few anticipated such high opening bids. This was an immediate indication that bidders would not bid the minimum. Jump bids would be common throughout the bidding. Indeed, the bid increments, which led to so much discussion before the auction, turned out not to play an important role in the bidding. The large bids in the opening round led many to speculate that the auction would conclude on Tuesday after only two days of bidding.[19] Like so many predictions this turned

19. "Many speculated, however, that the winning bidders would establish themselves by midday on Tuesday." *New York Times*, July 26, 1994, p. D1.

out to be far from true.[20] The auction would continue until Friday, only five hours before the bidding room (the Blue Room at Washington's Omni Shoreham Hotel) had to be cleared to begin preparations for a Saturday wedding.

In this section, I present the full history of bidding in the auction. The auction is of special interest because it is the first time the FCC used an auction to allocate spectrum. Moreover, the auction represents the first use of the simultaneous multiple-round auction, the auction form to be used in the broadband PCS auctions. Hence, this experience provides the best data available on bidding behavior in a simultaneous multiple-round auction. Much can be learned about the broadband auctions from a careful study of this bidding history.

4.1 SUMMARY OF THE BIDDING

The auction began on Monday morning, July 25, and concluded shortly before noon on Friday, July 29. The auction closed after 46 rounds. Figure 1 displays the total of the high bids and a measure of bidding activity, the number of new bids in each round. The total of the high bids increased rapidly early in the auction when bidder activity was high. As prices increased, bid activity declined as did the rate of increase in the total of the high bids.

Figure 2 displays the bid activity by license type.[21] Through the first 18 rounds, bidding was primarily on the 50/50s and 50/12.5s. After round 19, bidding stopped for six rounds on the 50/50s, but then resumed again in round 26, before concluding in round 37. Bidding on the 50/12.5s was heavy throughout the first half of the auction, but concluded in round 25, 21 rounds before the end of the auction. Bidding on the 50s was light and steady throughout the auction. The last nine rounds of the auction involved new bids on only the 50s. In the final eight rounds, there was just a single new bid in each round—three bidders were competing for two licenses.

Figure 3 shows the demand curves revealed by the bidding for each license type. Price is stated in $/MHz-pop (i.e., the cost of the license in dollars divided by the product of the size of the license in megahertz and the population covered, which is 250 million for a nationwide license) to make the prices among license types comparable. Indeed, one remarkable aspect of the bidding is that the final

20. By Thursday, participants were more cautious in their predictions: "But few people were willing to make firm predictions because almost nothing had gone as expected since the bidding opened on Monday." *New York Times*, July 29, 1994.

21. Bid activity in round one is not shown to make the figure more readable. In round one, there were 61 new bids: 30 on the 50/50s, 18 on the 50/12.5s, and 13 on the 50s.

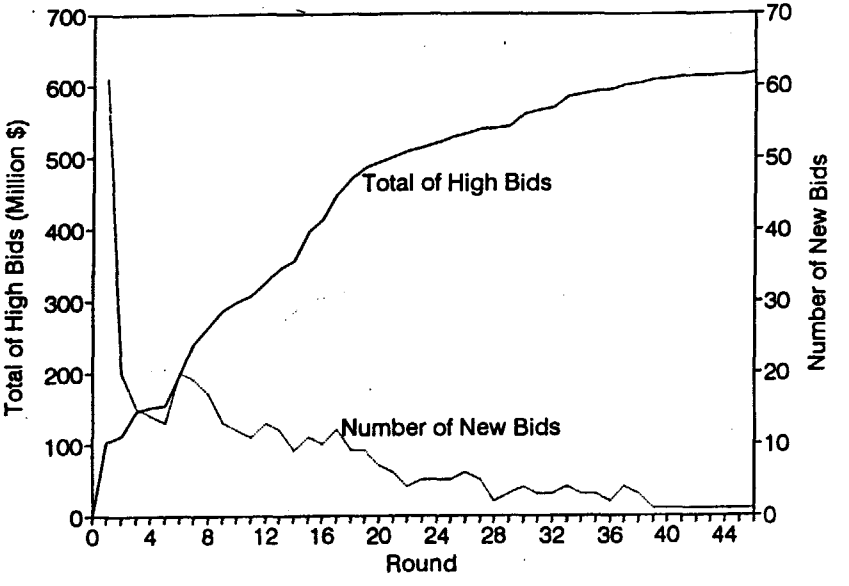

FIGURE 1. TOTAL SPENT AND BID ACTIVITY.

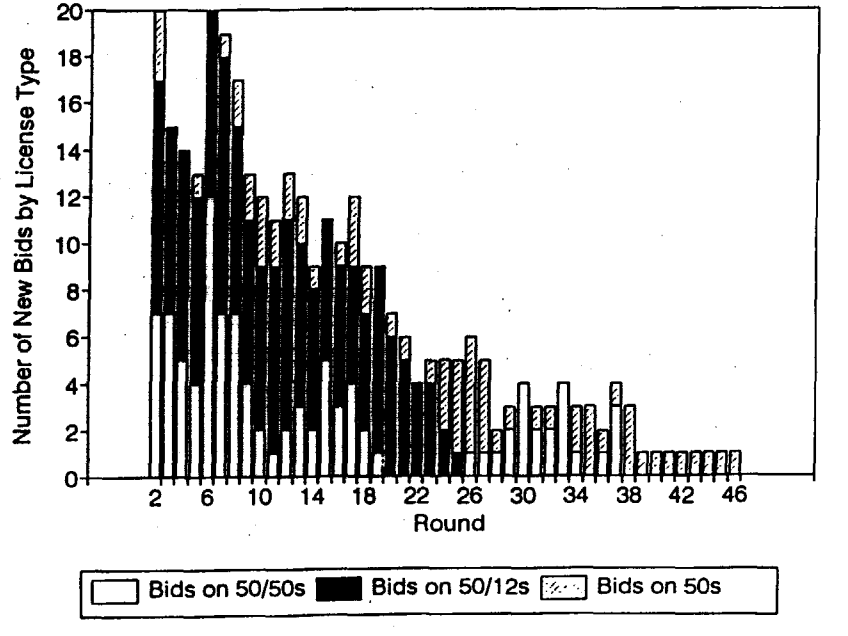

FIGURE 2. BID ACTIVITY BY LICENSE TYPE.

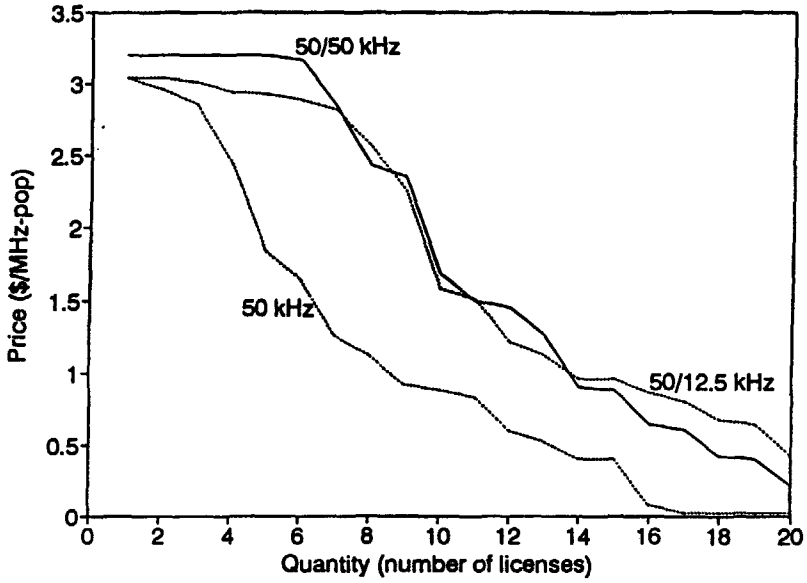

FIGURE 3. DEMAND BY LICENSE TYPE.

prices for all the licenses are nearly equal at about $3.00 per MHz-pop. Since there is no reason that firms should value inbound and outbound spectrum equally, the equality of prices across license types stems from the FCC's making the right choice about the supply of inbound spectrum relative to outbound spectrum.

Each of the demand curves is approximate. Because of the prevalence of jump bidding, it is impossible to know the exact price at which a bidder reduces its demand. Likewise, at the top of the demand curve, it is not known what the reservation prices of the high bidders are. It is only known that their walk-away prices were not reached. Finally, because of strategic bidding, the bids need not reflect the bidders' true valuations. A good example of strategic bidding was PageMart's bids of $71 million each on licenses 2 and 3 in round 29. These bids bumped both PageNet (the high bidder on license 2) and McCaw (the high bidder on license 3). At these prices, PageMart had an interest in a single 50/50 license, not two, but it knew that either PageNet or McCaw would surely respond to the challenge, and probably both. By bidding on both 2 and 3, PageMart was able to test both PageNet and McCaw in one round. This strategic bidding throws off the demand curve slightly, since PageMart is credited as having a demand for two 50/50s at a price of $71 million each. Another example of strategic bidding is the insincere low-bidding by several firms early

in the auction (those hiding in the grass). For this reason, I have cut off the bottom of the demand curves.

Figure 4 shows the revealed demand for nationwide narrowband spectrum. The demand curve is constructed by calculating each firm's aggregate demand for spectrum from the firm's bids (weighing inbound and outbound spectrum equally), and then summing these individual bidder demands. The FCC's supply curve is shown as the vertical line at a quantity of .7875 MHz. Like the demand curves in Figure 3, the market demand for spectrum derived from the bids is approximate. Nonetheless, it is possible to make at least a crude evaluation of the FCC's decision to withhold an additional third megahertz of narrowband spectrum from the narrowband auctions. If this third megahertz were divided like the first two megahertz, this would represent a 50% increase in the quantity supplied. From the demand curve, this increase in supply from .7875 to 1.181 MHz would result in the average price falling from $3.13 to $2.40 per MHz-pop. Hence, the FCC would collect $2.40 \times 1.181 \times 250 = \$708$ million, rather than $3.13 \times .7875 \times 250 = \$617$ million. The 50% increase in supply would result in a 15% increase in revenues. Given the relatively modest increase in revenues associated with a 50% increase in supply, a revenue maximizing FCC is probably better off waiting to sell the third megahertz. This is especially the case, since the $708 million may be an

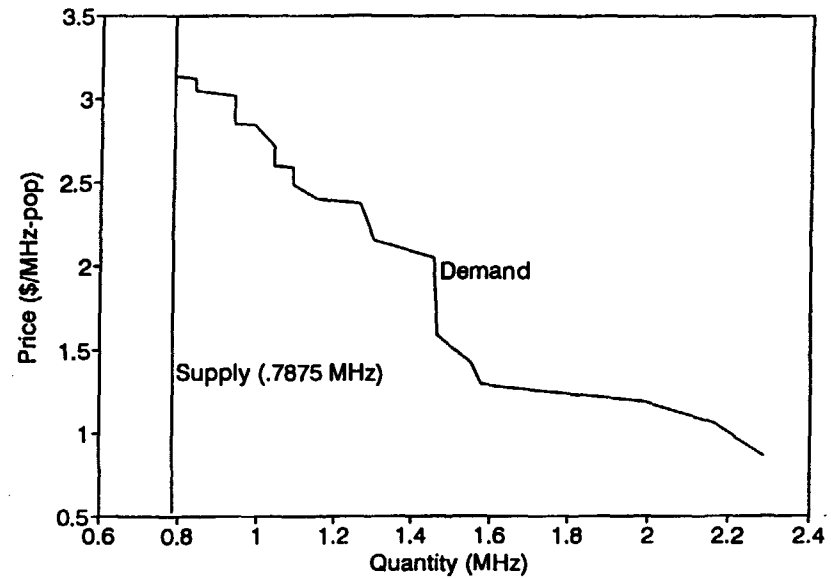

FIGURE 4. DEMAND FOR SPECTRUM.

overestimate of revenue. The demand curve on which the calculation is based relies on the assumption that supply is fixed at .7875 MHz until the FCC auctions the third megahertz. If supply is increased immediately, then scarce spectrum is less of a constraint on competition, hence competition is likely to be more intense, which reduces bidders' values, shifting the demand curve to the left. On the other hand, the FCC's objective is not to maximize revenues. The FCC's decision included the welfare of consumers, who would benefit through lower prices if more spectrum were allocated initially.

Tables VIIa–VIId present the bid increments, the high bids, the confidential bidder numbers, and the bidding activity in each round. Each round in the table is separated by a line. The first 5 rows in a round correspond to the five 50/50 kHz licenses (licenses 1 to 5); the next three rows are for the three 50/12.5 kHz licenses (licenses 6 to 8); and the next two rows are for the 50 kHz unpaired licenses (licenses 10 and 11). Each row gives the minimum bid increment, stated in both percentage and absolute terms, the minimum bid, the current high bid, the bidder number, and the number of new bids on the particular license (a blank cell means that there were no new bids).

Through round 21, the FCC roughly stuck to their 5% bid increment rule. Then in round 22, after three rounds of inactivity on the 50/50s, the FCC sharply dropped the bid increments on the 50/50s. Bidding on these licenses, however, continued to be independent of the bid increments. Activity on the 50/50s did not renew until the prices on the 50/12.5s increased to the point where one of the bidders was enticed to switch back to the 50/50s. The FCC continued to adjust bid increments in response to activity in the prior round, but always keeping the bid increment below 5%. In the last four rounds, the bid increments on the 50/50s and the 50/12.5s were all below .5%. Despite this low increment, there was no activity on these licenses. Clearly, the failure to attract further bids was an indication that the market clearing price had been reached; it was not the case that significant bid increments were keeping bidders from bidding. Even on the 50s, the last set of licenses to close, the FCC was able to drop the bid increment to less than 1.4%.

4.2 Bidding History

Tables VIIIa–VIIIg display all the bids of all the bidders for each round of the auction. This table is most useful in tracking the firms' bidding strategies. Indeed, during the auction, PageNet used these tables to track bidder behavior. The tables were stored in a spreadsheet that

displayed one round per screen. Hence, by flipping through the screens, one saw a "movie" of the bidding behavior, much like the flip books children have to see animation by flipping quickly through the pages. This format was very useful in getting a sense for firms' budget constraints and valuations by observing when firms would drop down to less valuable licenses or reduce their demands from three to two to one.

As before, each round in the table is separated by a line. Each row gives the bids placed by the bidders on a particular license. The first five rows are for the five 50/50s (licenses 1–5), the next three rows are for the three 50/12.5s (licenses 6–8), and the final two rows are for the two 50s (licenses 10–11). The high bid for a particular license appears in **bold.**

Although not shown in the tables, the spreadsheet also tracked bidder eligibility and the use of automatic waivers. The number of licenses a firm is eligible to bid on depends on the size of the upfront payment the bidder made. Most bidders made an upfront payment of $1,050,000, which makes them eligible for 3 licenses. Four bidders (McCaw, Mtel, PageNet, and Mobile Media) made an upfront payment of $3,500,000, which makes them eligible to bid on 10 licenses in any round. However, regardless of the upfront payment, no bidder is eligible to win more than three licenses.

There are two column headings. The first is the firm's abbreviated name for the top ten bidders, and the second heading is the bidder's confidential bidder number. For the top ten bidders, PageNet and other observant bidders were able to determine the bidders' identities by the end of the auction based on their bidding behavior. Bidder identities were uncovered by: (1) knowing the firms in the industry and their interests, (2) knowing how many licenses each firm was eligible to bid on, (3) observing whether a bid was placed and the time of the bid,[22] (4) observing whether a bidder "placing" a bid received a written confirmation of the bid,[23] and (5) observing who must have

22. The FCC inadvertently listed the bid entry times of all bids in two rounds.

23. It was common for a bidder that did not need to bid, because it was the current high bidder, to pretend to place a bid, so as to conceal its identity. These pretend bids were not always successful before round 18, because a bidder could not ask for written confirmation of the pretend bid. Almost all bidders asked for written confirmation of their bids. To get a written confirmation, the bid assistant would have to walk across the room in public view. In round 18, the FCC announced, "Beginning with this round, you may go into the bidding booth and request from the bidding assistant a confirmation of your actions regardless of whether you bid, exercise a proactive waiver, or do not submit a bid." Even this met with limited success, since the sheet on which the written confirmation was printed was folded differently depending on whether it was a real bid or a fake bid.

TABLE VIIA.

MINIMUM BID INCREMENTS, HIGH BIDS, AND BIDDER ACTIVITY—ROUNDS 1–12
(ALL AMOUNTS IN $K)

round/ license	%bid incr	bid incr	min bid	high bid	bidder ID	#new bids
1. 1		250	500	20,000	9683	6
2		250	500	10,000	5398	4
3		250	500	10,000	5398	5
4		250	500	10,000	5398	3
5		250	500	20,000	9683	12
6		150	300	6,250	5398	5
7		150	300	6,250	5398	6
8		150	300	6,250	5398	7
10		125	250	10,000	9683	10
11		125	250	5,000	5398	3
2. 1	5.0	1,000	21,000	20,000	9683	
2	5.0	500	10,500	10,500	8780	1
3	5.0	500	10,500	15,000	7884	5
4	5.0	500	10,500	10,500	1006	1
5	5.0	1,000	21,000	20,000	9683	
6	5.0	313	6,563	6,750	2109	5
7	5.0	313	6,563	6,600	7561	2
8	5.0	313	6,563	6,587	1666	3
10	5.0	500	10,500	10,000	9683	
11	5.0	250	5,250	6,500	7608	3
3. 1	5.0	1,000	21,000	20,000	9683	
2	5.0	525	11,025	15,111	1666	4
3	5.0	750	15,750	25,000	5398	1
4	5.0	525	11,025	25,000	5398	2
5	5.0	1,000	21,000	20,000	9683	
6	4.8	325	7,075	7,550	2109	2
7	4.9	325	6,925	10,000	5398	3
8	4.7	313	6,900	7,000	1942	3
10	5.0	500	10,500	10,000	9683	
11	5.0	325	6,825	6,500	7608	
4. 1	5.0	1,000	21,000	20,000	9683	
2	5.9	889	16,000	18,750	5403	5
3	5.0	1,250	26,250	25,000	5398	
4	5.0	1,250	26,250	25,000	5398	
5	5.0	1,000	21,000	20,000	9683	
6	5.0	375	7,925	8,111	5403	4
7	5.0	500	10,500	10,000	5398	
8	5.0	350	7,350	7,450	7561	5
10	5.0	500	10,500	10,000	9683	
11	5.0	325	6,825	6,500	7608	
5. 1	5.0	1,000	21,000	20,000	9683	
2	5.3	1,000	19,750	20,123	1666	4
3	5.0	1,250	26,250	25,000	5398	
4	5.0	1,250	26,250	25,000	5398	
5	5.0	1,000	21,000	20,000	9683	
6	4.8	389	8,500	8,600	7884	1
7	5.0	500	10,500	10,000	5398	
8	5.0	375	7,825	8,350	7446	7
10	5.0	500	10,500	10,000	9683	
11	5.0	325	6,825	6,825	5970	1
6. 1	5.0	1,000	21,000	30,000	9065	3
2	5.1	1,027	21,150	30,000	9065	5
3	5.0	1,250	26,250	30,000	9065	1
4	5.0	1,250	26,250	30,000	9065	1
5	5.0	1,000	21,000	30,000	9065	2
6	5.2	450	9,050	10,000	7561	2
7	5.0	500	10,500	10,000	5398	
8	5.1	425	8,775	10,000	7561	6
10	5.0	500	10,500	10,000	9683	
11	4.8	325	7,150	6,825	5970	

round/ license	%bid incr	bid incr	min bid	high bid	bidder ID	#new bids
7. 1	5.0	1,500	31,500	36,335	5017	2
2	5.0	1,500	31,500	30,000	9065	
3	5.0	1,500	31,500	40,000	5398	3
4	5.0	1,500	31,500	40,000	5398	1
5	5.0	1,500	31,500	35,000	9683	1
6	5.0	500	10,500	12,500	9683	3
7	5.0	500	10,500	15,000	5398	4
8	5.0	500	10,500	15,000	5398	4
10	5.0	500	10,500	10,000	9683	
11	4.8	325	7,150	7,159	1666	1
8. 1	5.1	1,840	38,175	42,000	9065	1
2	5.0	1,500	31,500	42,000	9065	5
3	5.0	2,000	42,000	42,000	9065	1
4	5.0	2,000	42,000	40,000	5398	
5	5.0	1,750	36,750	35,000	9683	
6	5.0	625	13,125	13,500	2109	7
7	5.0	750	15,750	15,000	5398	
8	5.0	750	15,750	17,512	7608	1
10	5.0	500	10,500	10,000	9683	
11	4.8	341	7,500	7,510	5970	2
9. 1	4.8	2,000	44,000	42,000	9065	
2	4.8	2,000	44,000	42,000	9065	
3	4.8	2,000	44,000	50,000	5398	1
4	5.0	2,000	42,000	50,000	5398	2
5	5.1	1,800	36,800	37,421	5403	1
6	5.0	675	14,175	15,001	8243	7
7	5.0	750	15,750	15,000	5398	
8	4.8	839	18,350	17,512	7608	
10	4.0	400	10,400	10,000	9683	
11	5.2	390	7,900	7,909	1666	2
10. 1	4.8	2,000	44,000	42,000	9065	
2	4.8	2,000	44,000	42,000	9065	
3	4.0	2,000	52,000	50,000	5398	
4	4.0	2,000	52,000	50,000	5398	
5	5.0	1,879	39,300	45,509	5017	2
6	5.0	749	15,750	16,110	8780	5
7	5.0	750	15,750	16,005	1666	2
8	4.8	839	18,350	17,512	7608	
10	4.0	400	10,400	10,000	9683	
11	4.9	391	8,300	8,500	2109	3
11. 1	4.8	2,000	44,000	45,000	9683	1
2	4.8	2,000	44,000	42,000	9065	
3	4.0	2,000	52,000	50,000	5398	
4	4.0	2,000	52,000	50,000	5398	
5	4.4	1,991	47,500	45,509	5017	
6	4.9	790	16,900	20,000	9065	2
7	5.0	795	16,800	17,776	8243	6
8	4.8	839	18,350	17,512	7608	
10	4.0	400	10,400	10,000	9683	
11	5.0	425	8,925	9,009	1666	2
12. 1	4.4	2,000	47,000	50,000	9065	1
2	4.8	2,000	44,000	50,000	9065	1
3	4.0	2,000	52,000	50,000	5398	
4	4.0	2,000	52,000	50,000	5398	
5	4.4	1,991	47,500	45,509	5017	
6	3.0	600	20,600	20,000	9065	
7	4.9	874	18,650	19,001	1006	3
8	4.8	839	18,350	20,000	7561	6
10	4.0	400	10,400	10,000	9683	
11	5.2	466	9,475	10,100	2109	2

TABLE VIIB.

MINIMUM BID INCREMENTS, HIGH BIDS, AND BIDDER ACTIVITY—ROUNDS 13–24

(ALL AMOUNTS IN $K)

round/ license	%bid incr	bid incr	min bid	high bid	bidder ID	#new bids
13. 1	4.0	2,000	52,000	50,000	9065	
2	4.0	2,000	52,000	50,000	9065	
3	4.0	2,000	52,000	50,000	5398	
4	4.0	2,000	52,000	50,000	5398	
5	4.4	1,991	47,500	50,289	1666	3
6	3.0	600	20,600	30,000	9065	1
7	5.0	949	19,950	20,978	8243	5
8	3.0	600	20,600	21,002	8780	1
10	4.0	400	10,400	10,500	7561	1
11	3.0	300	10,400	10,400	7446	1
14. 1	5.0	2,500	52,500	50,000	9065	
2	5.0	2,500	52,500	50,000	9065	
3	5.0	2,500	52,500	52,800	9683	1
4	5.0	2,500	52,500	50,000	5398	
5	4.4	2,211	52,500	55,489	5017	1
6	3.3	1,000	31,000	30,000	9065	
7	4.9	1,022	22,000	22,500	7561	5
8	4.8	998	22,000	22,254	1006	1
10	3.8	400	10,900	11,000	9683	1
11	4.8	500	10,900	10,400	7446	
15. 1	5.0	2,500	52,500	60,000	9065	1
2	5.0	2,500	52,500	60,000	9065	1
3	4.2	2,200	55,000	60,000	5398	1
4	5.0	2,500	52,500	60,000	5398	2
5	4.5	2,511	58,000	55,489	5017	
6	3.3	1,000	31,000	30,000	9065	
7	4.9	1,100	23,600	24,000	7884	2
8	5.1	1,146	23,400	24,687	8243	4
10	4.5	500	11,500	11,000	9683	
11	4.8	500	10,900	10,400	7446	
16. 1	5.0	3,000	63,000	60,000	9065	
2	5.0	3,000	63,000	60,000	9065	
3	5.0	3,000	63,000	60,000	5398	
4	5.0	3,000	63,000	60,000	5398	
5	4.5	2,511	58,000	60,727	5017	3
6	3.3	1,000	31,000	32,000	7884	1
7	5.0	1,200	25,200	28,828	1006	4
8	4.9	1,213	25,900	26,123	5403	1
10	4.5	500	11,500	13,500	1942	1
11	4.8	500	10,900	10,400	7446	
17. 1	5.0	3,000	63,000	60,000	9065	
2	5.0	3,000	63,000	63,000	9683	1
3	5.0	3,000	63,000	70,000	5398	2
4	5.0	3,000	63,000	70,000	5398	1
5	3.7	2,273	63,000	60,727	5017	
6	4.7	1,500	33,500	32,000	7884	
7	5.0	1,447	30,275	40,000	9065	2
8	5.1	1,327	27,450	27,685	8780	3
10	3.7	500	14,000	13,500	1942	
11	4.8	500	10,900	11,000	7561	3
18. 1	5.0	3,000	63,000	70,000	9065	1
2	4.8	3,000	66,000	70,000	9065	1
3	5.0	3,500	73,500	70,000	5398	
4	5.0	3,500	73,500	70,000	5398	
5	3.7	2,273	63,000	60,727	5017	
6	4.7	1,500	33,500	32,000	7884	
7	5.0	2,000	42,000	40,000	9065	
8	5.1	1,415	29,100	32,000	7884	5
10	3.7	500	14,000	13,500	1942	
11	4.5	500	11,500	12,078	8243	2
19. 1	5.0	3,500	73,500	70,000	9065	
2	5.0	3,500	73,500	70,000	9065	
3	5.0	3,500	73,500	70,000	5398	
4	5.0	3,500	73,500	70,000	5398	
5	3.7	2,273	63,000	69,000	9683	1
6	4.7	1,500	33,500	35,000	7884	3
7	5.0	2,000	42,000	40,000	9065	
8	4.7	1,500	33,500	35,278	8780	5
10	3.7	500	14,000	13,500	1942	
11	4.3	522	12,600	12,078	8243	
20. 1	5.0	3,500	73,500	70,000	9065	
2	5.0	3,500	73,500	70,000	9065	
3	5.0	3,500	73,500	70,000	5398	
4	5.0	3,500	73,500	70,000	5398	
5	5.0	3,450	72,450	69,000	9683	
6	5.0	1,750	36,750	40,001	2055	4
7	5.0	2,000	42,000	40,000	9065	
8	4.2	1,472	36,750	38,100	7884	2
10	3.7	500	14,000	14,010	1006	1
11	4.3	522	12,600	12,078	8243	
21. 1	2.9	2,000	72,000	70,000	9065	
2	2.9	2,000	72,000	70,000	9065	
3	2.9	2,000	72,000	70,000	5398	
4	2.9	2,000	72,000	70,000	5398	
5	2.9	2,000	71,000	69,000	9683	
6	5.0	1,999	42,000	40,001	2055	
7	4.5	2,000	42,000	44,000	1666	1
8	4.7	1,900	40,000	40,679	5403	4
10	3.3	490	14,500	15,000	1942	1
11	4.3	522	12,600	12,078	8243	
22. 1	1.4	1,000	71,000	70,000	9065	
2	1.4	1,000	71,000	70,000	9065	
3	1.4	1,000	71,000	70,000	5398	
4	1.4	1,000	71,000	70,000	5398	
5	1.4	1,000	70,000	69,000	9683	
6	5.0	1,999	42,000	45,000	9065	2
7	4.5	2,000	46,000	44,000	1666	
8	4.5	1,821	42,500	43,697	1006	2
10	3.3	500	15,500	15,000	1942	
11	4.3	522	12,600	12,078	8243	
23. 1	0.7	500	70,500	70,000	9065	
2	0.7	500	70,500	70,000	9065	
3	0.7	500	70,500	70,000	5398	
4	0.7	500	70,500	70,000	5398	
5	0.7	500	69,500	69,000	9683	
6	3.3	1,500	46,500	45,000	9065	
7	3.4	1,500	45,500	45,750	7884	1
8	3.4	1,503	45,200	45,901	5403	3
10	2.0	300	15,300	15,000	1942	
11	2.7	322	12,400	12,400	9683	1
24. 1	0.4	250	70,250	70,000	9065	
2	0.4	250	70,250	70,000	9065	
3	0.4	250	70,250	70,000	5398	
4	0.4	250	70,250	70,000	5398	
5	0.4	250	69,250	69,000	9683	
6	3.3	1,500	46,500	47,001	7561	1
7	3.3	1,500	47,250	45,750	7884	
8	3.3	1,499	47,400	47,500	7884	1
10	2.0	300	15,300	15,000	1942	
11	2.4	300	12,700	15,000	9683	3

TABLE VIIC.

MINIMUM BID INCREMENTS, HIGH BIDS, AND BIDDER ACTIVITY—ROUNDS 25–36

(ALL AMOUNTS IN $K)

round/ license	%bid incr	bid incr	min bid	high bid	bidder ID	#new bids
25. 1	0.4	250	70,250	70,000	9065	
2	0.4	250	70,250	70,000	9065	
3	0.4	250	70,250	70,000	5398	
4	0.4	250	70,250	70,000	5398	
5	0.4	250	69,250	69,000	9683	
6	3.2	1,499	48,500	47,001	7561	
7	3.3	1,500	47,250	47,506	1006	1
8	3.2	1,500	49,000	47,500	7884	
10	2.0	300	15,300	20,000	9065	2
11	2.0	300	15,300	15,776	8243	2
26. 1	0.4	250	70,250	70,000	9065	
2	0.4	250	70,250	70,000	9065	
3	0.4	250	70,250	70,000	5398	
4	0.4	250	70,250	70,000	5398	
5	0.4	250	69,250	70,000	7884	1
6	3.2	1,499	48,500	47,001	7561	
7	3.1	1,494	49,000	47,506	1006	
8	3.2	1,500	49,000	47,500	7884	
10	3.8	750	20,750	20,000	9065	
11	4.6	724	16,500	20,750	1942	5
27. 1	0.4	250	70,250	70,000	9065	
2	0.4	250	70,250	70,000	9065	
3	0.4	250	70,250	70,000	5398	
4	0.4	250	70,250	70,000	5398	
5	0.4	250	70,250	70,250	9683	1
6	2.1	999	48,000	47,001	7561	
7	2.1	994	48,500	47,506	1006	
8	2.1	1,000	48,500	47,500	7884	
10	2.5	500	20,500	25,000	9065	3
11	2.4	500	21,250	21,806	5403	1
28. 1	0.4	250	70,250	70,000	9065	
2	0.4	250	70,250	70,000	9065	
3	0.4	250	70,250	70,000	5398	
4	0.4	250	70,250	70,000	5398	
5	0.4	250	70,500	71,000	7884	1
6	0.5	249	47,250	47,001	7561	
7	0.5	244	47,750	47,506	1006	
8	0.5	250	47,750	47,500	7884	
10	1.0	250	25,250	25,000	9065	
11	1.1	244	22,050	22,050	1942	1
29. 1	0.4	250	70,250	70,000	9065	
2	0.4	250	70,250	71,000	9683	1
3	0.4	250	70,250	71,000	9683	1
4	0.4	250	70,250	70,000	5398	
5	0.4	250	71,250	71,000	7884	
6	0.5	249	47,250	47,001	7561	
7	0.5	244	47,750	47,506	1006	
8	0.5	250	47,750	47,500	7884	
10	1.0	250	25,250	25,000	9065	
11	1.1	250	22,300	22,457	5403	1
30. 1	1.4	1,000	71,000	75,000	9065	1
2	1.4	1,000	72,000	75,000	9065	1
3	1.4	1,000	72,000	75,000	5398	1
4	1.4	1,000	71,000	75,000	5398	1
5	1.4	1,000	72,000	71,000	7884	
6	0.5	249	47,250	47,001	7561	
7	0.5	244	47,750	47,506	1006	
8	0.5	250	47,750	47,500	7884	
10	2.0	500	25,500	25,000	9065	
11	2.4	543	23,000	22,457	5403	
31. 1	1.3	1,000	76,000	75,000	9065	
2	1.3	1,000	76,000	75,000	9065	
3	1.3	1,000	76,000	75,000	5398	
4	1.3	1,000	76,000	75,000	5398	
5	1.4	1,000	72,000	75,000	7884	2
6	0.5	249	47,250	47,001	7561	
7	0.5	244	47,750	47,506	1006	
8	0.5	250	47,750	47,500	7884	
10	2.0	500	25,500	25,000	9065	
11	2.4	543	23,000	23,000	1942	1
32. 1	1.3	1,000	76,000	75,000	9065	
2	1.3	1,000	76,000	76,000	9683	1
3	1.3	1,000	76,000	75,000	5398	
4	1.3	1,000	76,000	75,000	5398	
5	1.3	1,000	76,000	77,000	7884	1
6	0.5	249	47,250	47,001	7561	
7	0.5	244	47,750	47,506	1006	
8	0.5	250	47,750	47,500	7884	
10	3.0	750	25,750	25,000	9065	
11	3.3	750	23,750	23,987	5403	1
33. 1	1.3	1,000	76,000	78,000	9065	1
2	1.3	1,000	77,000	78,000	9065	1
3	1.3	1,000	76,000	80,000	5398	1
4	1.3	1,000	76,000	80,000	5398	1
5	1.3	1,000	78,000	77,000	7884	
6	0.5	249	47,250	47,001	7561	
7	0.5	244	47,750	47,506	1006	
8	0.5	250	47,750	47,500	7884	
10	3.0	750	25,750	25,000	9065	
11	3.2	763	24,750	23,987	5403	
34. 1	1.3	1,000	79,000	78,000	9065	
2	1.3	1,000	79,000	78,000	9065	
3	1.3	1,000	81,000	80,000	5398	
4	1.3	1,000	81,000	80,000	5398	
5	1.3	1,000	78,000	79,000	7884	1
6	0.5	249	47,250	47,001	7561	
7	0.5	244	47,750	47,506	1006	
8	0.5	250	47,750	47,500	7884	
10	2.0	500	25,500	25,000	9065	
11	2.1	513	24,500	25,750	1942	2
35. 1	1.3	1,000	79,000	78,000	9065	
2	1.3	1,000	79,000	78,000	9065	
3	1.3	1,000	81,000	80,000	5398	
4	1.3	1,000	81,000	80,000	5398	
5	1.3	1,000	80,000	79,000	7884	
6	0.5	249	47,250	47,001	7561	
7	0.5	244	47,750	47,506	1006	
8	0.5	250	47,750	47,500	7884	
10	4.0	1,000	26,000	28,000	9065	2
11	3.9	1,000	26,750	26,875	5403	1
36. 1	1.3	1,000	79,000	79,000	9683	1
2	1.3	1,000	79,000	78,000	9065	
3	1.3	1,000	81,000	80,000	5398	
4	1.3	1,000	81,000	80,000	5398	
5	1.3	1,000	80,000	79,000	7884	
6	0.5	249	47,250	47,001	7561	
7	0.5	244	47,750	47,506	1006	
8	0.5	250	47,750	47,500	7884	
10	3.6	1,000	29,000	29,000	1942	1
11	4.2	1,125	28,000	26,875	5403	

TABLE VIID.

MINIMUM BID INCREMENTS, HIGH BIDS, AND BIDDER ACTIVITY—ROUNDS 37–47

(ALL AMOUNTS IN $K)

round/ license	%bid incr	bid incr	min bid	high bid	bidder ID	#new bids
37. 1	1.3	1,000	80,000	80,000	9065	1
2	1.3	1,000	79,000	80,000	9065	1
3	1.3	1,000	81,000	80,000	5398	
4	1.3	1,000	81,000	80,000	5398	
5	1.3	1,000	80,000	80,000	7884	1
6	0.5	249	47,250	47,001	7561	
7	0.5	244	47,750	47,506	1006	
8	0.5	250	47,750	47,500	7884	
10	3.4	1,000	30,000	29,000	1942	
11	4.2	1,125	28,000	29,000	9065	1
38. 1	3.1	2,500	82,500	80,000	9065	
2	3.1	2,500	82,500	80,000	9065	
3	3.1	2,500	82,500	80,000	5398	
4	3.1	2,500	82,500	80,000	5398	
5	3.1	2,500	82,500	80,000	7884	
6	0.5	249	47,250	47,001	7561	
7	0.5	244	47,750	47,506	1006	
8	0.5	250	47,750	47,500	7884	
10	4.0	1,250	30,250	31,000	9683	2
11	4.1	1,250	30,250	30,377	5403	1
39. 1	3.1	2,500	82,500	80,000	9065	
2	3.1	2,500	82,500	80,000	9065	
3	3.1	2,500	82,500	80,000	5398	
4	3.1	2,500	82,500	80,000	5398	
5	3.1	2,500	82,500	80,000	7884	
6	0.5	249	47,250	47,001	7561	
7	0.5	244	47,750	47,506	1006	
8	0.5	250	47,750	47,500	7884	
10	4.8	1,500	32,500	31,000	9683	
11	4.9	1,473	31,850	35,000	9065	1
40. 1	3.1	2,500	82,500	80,000	9065	
2	3.1	2,500	82,500	80,000	9065	
3	3.1	2,500	82,500	80,000	5398	
4	3.1	2,500	82,500	80,000	5398	
5	3.1	2,500	82,500	80,000	7884	
6	0.5	249	47,250	47,001	7561	
7	0.5	244	47,750	47,506	1006	
8	0.5	250	47,750	47,500	7884	
10	4.8	1,500	32,500	32,554	5403	1
11	4.3	1,500	36,500	35,000	9065	
41. 1	1.3	1,000	81,000	80,000	9065	
2	1.3	1,000	81,000	80,000	9065	
3	1.3	1,000	81,000	80,000	5398	
4	1.3	1,000	81,000	80,000	5398	
5	1.3	1,000	81,000	80,000	7884	
6	0.5	249	47,250	47,001	7561	
7	0.5	244	47,750	47,506	1006	
8	0.5	250	47,750	47,500	7884	
10	1.7	546	33,100	34,500	9683	1
11	1.4	500	35,500	35,000	9065	
42. 1	1.3	1,000	81,000	80,000	9065	
2	1.3	1,000	81,000	80,000	9065	
3	1.3	1,000	81,000	80,000	5398	
4	1.3	1,000	81,000	80,000	5398	
5	1.3	1,000	81,000	80,000	7884	
6	0.5	249	47,250	47,001	7561	
7	0.5	244	47,750	47,506	1006	
8	0.5	250	47,750	47,500	7884	
10	1.4	500	35,000	35,726	5403	1
11	1.4	500	35,500	35,000	9065	
43. 1	1.3	1,000	81,000	80,000	9065	
2	1.3	1,000	81,000	80,000	9065	
3	1.3	1,000	81,000	80,000	5398	
4	1.3	1,000	81,000	80,000	5398	
5	1.3	1,000	81,000	80,000	7884	
6	0.5	249	47,250	47,001	7561	
7	0.5	244	47,750	47,506	1006	
8	0.5	250	47,750	47,500	7884	
10	1.4	499	36,225	36,500	9683	1
11	1.4	500	35,500	35,000	9065	
44. 1	0.3	250	80,250	80,000	9065	
2	0.3	250	80,250	80,000	9065	
3	0.3	250	80,250	80,000	5398	
4	0.3	250	80,250	80,000	5398	
5	0.3	250	80,250	80,000	7884	
6	0.5	249	47,250	47,001	7561	
7	0.5	244	47,750	47,506	1006	
8	0.5	250	47,750	47,500	7884	
10	1.4	500	37,000	36,500	9683	
11	1.4	500	35,500	35,726	5403	1
45. 1	0.3	250	80,250	80,000	9065	
2	0.3	250	80,250	80,000	9065	
3	0.3	250	80,250	80,000	5398	
4	0.3	250	80,250	80,000	5398	
5	0.3	250	80,250	80,000	7884	
6	0.5	249	47,250	47,001	7561	
7	0.5	244	47,750	47,506	1006	
8	0.5	250	47,750	47,500	7884	
10	1.4	500	37,000	37,000	9065	1
11	1.4	499	36,225	35,726	5403	
46. 1	0.3	250	80,250	80,000	9065	
2	0.3	250	80,250	80,000	9065	
3	0.3	250	80,250	80,000	5398	
4	0.3	250	80,250	80,000	5398	
5	0.3	250	80,250	80,000	7884	
6	0.5	249	47,250	47,001	7561	
7	0.5	244	47,750	47,506	1006	
8	0.5	250	47,750	47,500	7884	
10	1.4	500	37,500	37,000	9065	
11	1.4	499	36,225	38,000	9683	1
47. 1	0.3	250	80,250	80,000	9065	
2	0.3	250	80,250	80,000	9065	
3	0.3	250	80,250	80,000	5398	
4	0.3	250	80,250	80,000	5398	
5	0.3	250	80,250	80,000	7884	
6	0.5	249	47,250	47,001	7561	
7	0.5	244	47,750	47,506	1006	
8	0.5	250	47,750	47,500	7884	
10	1.4	500	37,500	37,000	9065	
11	1.3	500	38,500	38,000	9683	

TABLE VIIIA.

BIDDING HISTORY—ROUNDS 1–6 (ALL AMOUNTS IN $K; HIGH BIDS IN BOLD)

Firm		BellS	McCaw	AirTch	Mtel	PageNet	PMart	AmerP	Dubis	MobileM	USWest							
ID		1006	5398	7561	7884	9065	9683	5403	1942	1666	8780	8243	2055	5017	7446	2109	7608	5970
1.	1		10,000		500		20,000	511		5,432	1,050							
	2	500	10,000		500					5,667								
	3		10,000		500					5,333		501	500					
	4		10,000		500					5,111								
	5		10,000		500		20,000		523	5,222					500		750	750
	6		6,250		300			333		1,111						395		
	7		6,250		300					1,222				300		395		
	8		6,250		300					1,121					300	395		
	10		5,000	250	250	250	10,000	276		1,000								
	11		5,000		250					1,222								
2.	1						20,000											
	2		10,000								10,500							
	3		10,000		15,000			10,678		10,687			10,500	10,500				
	4	10,500	10,000															
	5						20,000											
	6		6,250		6,563	6,563		6,653				6,601				6,750		
	7		6,250	6,600	6,563													
	8		6,250		6,563					6,587					6,563			
	10						10,000											
	11		5,000						5,479								6,500	5,250
3.	1						20,000											
	2							11,556		15,111	10,500		11,500	11,025				
	3		25,000		15,000													
	4	10,500	25,000							15,111								
	5						20,000											
	6											7,101				7,550		
	7		10,000	6,600	7,000			6,988										
	8					6,917			7,000	6,587					6,900			
	10						10,000											
	11																6,500	
4.	1						20,000											
	2							18,750		15,111	16,325		17,778	16,000				16,000
	3		25,000															
	4		25,000															
	5						20,000											
	6				8,000			8,111				8,001				8,075		
	7		10,000												7,350			
	8	7,350		7,450	7,400	7,350			7,000									
	10						10,000										6,500	
	11																	
5.	1						20,000											
	2							18,750		20,123	20,001		20,000	19,750				
	3		25,000															
	4		25,000															
	5						20,000											
	6				8,600			8,111										
	7		10,000												8,350	8,075		
	8	7,850		7,450	7,900	7,825			8,050			7,826						
	10						10,000										6,500	6,825
	11																	
6.	1					30,000	25,000	21,373										
	2				21,500	30,000				20,123	22,525		22,000	21,151				
	3		25,000			30,000												
	4		25,000			30,000												
	5					30,000	25,000											
	6			10,000	8,600			9,111										
	7		10,000															
	8	9,500		10,000					8,875			8,801			8,350	9,051	8,800	
	10						10,000											6,825
	11																	

Notes: Each column gives the bidder's bids for each license by round. Each round is separated by a line. Within a round the first five rows give the bids for the five 50/50 kHz licenses, the next three rows give the bids for the three 50/12.5 kHz licenses, and the next two rows give the bids for the two 50 kHz licenses. The first row, "Firm", indicates the identity of the top-ten bidders: BellS = Bell South Wireless, McCaw = KDM Messaging Company (a wholly-owned subsidiary of McCaw Cellular Communications), AirTch = AirTouch Paging, Mtel = Nationwide Wireless Network (a subsidiary of Mtel (80.6%), Microsoft (8.5%), William Gates (2.8%) and Paul Allen (2.8%)), PageNet = Paging Network, PMart = PageMart, AmerP = American Paging (USA Mobile Communications), Dubis = Dubis Communications, MobileM = Mobile Media Communications, USWest = US West Communications. The second row, "ID", is the confidential number used to identify the bidders. Winning bidders appear in the left-most columns with the remaining bidders ordered based on how long they remained in the auction. Eight bidders dropped out after the first round. Their bids follow: 1027 bid $260k on license 10, 1061 bid $525k on license 5, 1168 bid $300k on license 8, 1865 bid $500k on license 5, 2073 bid $250k on license 10, 6045 bid $500k on license 5, 8718 bid $510k on license 5 and $310 on license 8, 9438 bid $331k on license 7 and $276k on license 10.

TABLE VIIIB.

BIDDING HISTORY—ROUNDS 7–12 (ALL AMOUNTS IN $K; HIGH BIDS IN BOLD)

Firm ID	BellS 1006	McCaw 5398	AirTch 7561	Mtel 7884	PageNet 9065	PMart 9683	AmerP 5403	Dubis 1942	MobileM 1666	USWest 8780	8243	2055	5017	7446	2109	7608	5970
7. 1					30,000		31,875						36,335				
2					30,000												
3		40,000		32,000	30,000								36,335				
4		40,000			30,000												
5					30,000	35,000											
6	12,000		10,000			12,500				10,500							
7		15,000									11,001	10,778			11,510		
8		15,000	10,000					10,825						10,501		10,600	
10						10,000											
11									7,159								6,825
8. 1					42,000								36,335				
2				32,000	42,000		32,450	31,500					37,021				
3		40,000			42,000												
4		40,000															
5						35,000											
6	13,130		13,500			12,500			13,125	13,250	13,126	13,125			13,500		
7		15,000															
8		15,000														17,512	
10						10,000											
11									7,159					7,500			7,510
9. 1					42,000												
2					42,000												
3		50,000			42,000												
4		50,000											42,669				
5						35,000	37,421										
6	14,200		14,300	14,200				14,175		14,500	15,001	14,177			13,500		
7		15,000															
8																17,512	
10						10,000											
11									7,909					7,900			7,510
10. 1					42,000												
2					42,000												
3		50,000															
4		50,000															
5					43,000		37,421						45,509				
6			15,800	16,000				15,751		16,110	15,001	15,750					
7	16,001	15,000							16,005								
8																17,512	
10						10,000											
11									7,909		8,301			8,300	8,500		
11. 1					42,000	45,000											
2					42,000												
3		50,000															
4		50,000															
5													45,509				
6			17,500		20,000					16,110							
7	17,102			17,000			16,967	16,800	16,005		17,776	16,800					
8																17,512	
10						10,000											
11									9,009					8,925	8,500		
12. 1					50,000	45,000											
2					50,000												
3		50,000															
4		50,000															
5													45,509				
6					20,000												
7	19,001			19,000			18,889				17,776						
8	19,001		20,000					18,355	18,360	18,500		18,350				17,512	
10						10,000											
11									9,009					9,475	10,100		

TABLE VIIIC.

BIDDING HISTORY—ROUNDS 13–18 (ALL AMOUNTS IN $K; HIGH BIDS IN BOLD)

Firm ID	BellS 1006	McCaw 5398	AirTch 7561	Mtel 7884	PageNet 9065	PMart 9683	AmerP 5403	Dubis 1942	MobileM 1666	USWest 8780	8243	2055	5017	7446	2109
13. 1					**50,000**										
2					**50,000**										
3		50,000													
4		50,000													
5						50,000			50,289				50,183		
6					**30,000**										
7	19,001			20,000			20,108	20,103			20,978	19,950			
8			20,000							21,002					
10			10,500			10,000									
11														10,400	10,100
14. 1					**50,000**										
2					**50,000**										
3		50,000				52,800									
4		50,000													
5									50,289				55,489		
6					**30,000**										
7			22,500	22,200			22,321	22,123			20,978	22,000			
8	22,254									21,002					
10			10,500			11,000									
11														10,400	
15. 1					**60,000**										
2					**60,000**										
3		60,000				52,800									
4		60,000							56,457						
5													55,489		
6					**30,000**										
7			22,500	24,000				23,612							
8	22,254						23,651			23,512	24,687	23,400			
10						11,000									
11														10,400	
16. 1					**60,000**										
2					**60,000**										
3		60,000													
4		60,000													
5						60,000			58,751				60,727		
6				32,000	30,000										
7	28,828		25,200	24,000						25,235		25,200			
8							26,123				24,687				
10						11,000		13,500							
11														10,400	
17. 1					**60,000**										
2					**60,000**	63,000									
3		70,000				63,000									
4		70,000													
5													60,727		
6				32,000											
7	28,828			32,000	40,000										
8							26,123		27,463	27,685		27,450			
10								13,500							
11			11,000								10,901			10,400	11,000
18. 1					**70,000**										
2					**70,000**	63,000									
3		70,000													
4		70,000													
5													60,727		
6				32,000											
7					40,000										
8	29,100			32,000			29,457		29,110	27,685		29,100			
10								13,500							
11			11,000								12,078				11,550

TABLE VIIID.

BIDDING HISTORY—ROUNDS 19–24 (ALL AMOUNTS IN $K; HIGH BIDS IN BOLD)

Firm ID	BellS 1006	McCaw 5398	AirTch 7561	Mtel 7884	PageNet 9065	PMart 9683	AmerP 5403	Dubis 1942	MobileM 1666	USWest 8780	8243	2055	5017
19. 1					**70,000**								
2					**70,000**								
3		**70,000**											
4		**70,000**											
5						**69,000**							60,727
6	34,010		33,600	35,000									
7					**40,000**								
8				35,000			33,711		33,588	35,278		33,500	
10								**13,500**					
11											**12,078**		
20. 1					**70,000**								
2					**70,000**								
3		**70,000**											
4		**70,000**											
5						**69,000**							
6			37,000	38,100					36,800			**40,001**	
7					**40,000**								
8				**38,100**			37,285			35,278			
10	**14,010**							13,500					
11											**12,078**		
21. 1					**70,000**								
2					**70,000**								
3		**70,000**											
4		**70,000**											
5						**69,000**							
6												**40,001**	
7					40,000				**44,000**				
8	40,510		40,010	40,500			**40,679**						
10	14,010							**15,000**					
11											**12,078**		
22. 1					**70,000**								
2					**70,000**								
3		**70,000**											
4		**70,000**											
5						**69,000**							
6				42,100	45,000							40,001	
7									**44,000**				
8	**43,697**		42,625				40,679						
10								**15,000**					
11											**12,078**		
23. 1					**70,000**								
2					**70,000**								
3		**70,000**											
4		**70,000**											
5						**69,000**							
6					**45,000**								
7				**45,750**					**44,000**				
8	43,697		45,500	45,750			**45,901**						
10								**15,000**					
11						**12,400**					12,078		
24. 1					**70,000**								
2					**70,000**								
3		**70,000**											
4		**70,000**											
5						**69,000**							
6			**47,001**		**45,000**								
7				**45,750**									
8				**47,500**			**45,901**						
10								**15,000**					
11						**15,000**			**12,783**		12,776		

TABLE VIIIE.

BIDDING HISTORY—ROUNDS 25–30 (ALL AMOUNTS IN $K; HIGH BIDS IN BOLD)

Firm ID		BellS 1006	McCaw 5398	AirTch 7561	Mtel 7884	PageNet 9065	PMart 9683	AmerP 5403	Dubis 1942	MobileM 1666	USWest 8780	8243
25.	1					70,000						
	2					70,000						
	3		70,000									
	4		70,000									
	5						69,000					
	6			47,001								
	7	47,506			45,750							
	8				47,500							
	10					20,000			15,000	16,006		
	11						15,000	15,701				15,776
26.	1					70,000						
	2					70,000						
	3		70,000									
	4		70,000									
	5				70,000		69,000					
	6			47,001								
	7	47,506										
	8				47,500							
	10					20,000						
	11						16,500	17,457	20,750	18,350	16,988	15,776
27.	1					70,000						
	2					70,000						
	3		70,000									
	4		70,000									
	5				70,000		70,250					
	6			47,001								
	7	47,506										
	8				47,500							
	10					25,000				23,009	20,559	
	11							21,806	20,750			
28.	1					70,000						
	2					70,000						
	3		70,000									
	4		70,000									
	5				71,000		70,250					
	6			47,001								
	7	47,506										
	8				47,500							
	10					25,000						
	11							21,806	22,050			
29.	1					70,000						
	2					70,000	71,000					
	3		70,000				71,000					
	4		70,000									
	5				71,000							
	6			47,001								
	7	47,506										
	8				47,500							
	10					25,000						
	11							22,457	22,050			
30.	1					75,000						
	2					75,000	71,000					
	3		75,000				71,000					
	4		75,000									
	5				71,000							
	6			47,001								
	7	47,506										
	8				47,500							
	10					25,000						
	11							22,457				

TABLE VIIIF.

BIDDING HISTORY—ROUNDS 31–39 (ALL AMOUNTS IN $K; HIGH BIDS IN BOLD)

Firm ID	BellS 1006	McCaw 5398	AirTch 7561	Mtel 7884	PageNet 9065	PMart 9683	AmerP 5403	Dubis 1942
31. 1					**75,000**			
2					**75,000**			
3		**75,000**						
4		**75,000**						
5				**75,000**		**72,000**		
6			**47,001**					
7	**47,506**							
8				**47,500**				
10					**25,000**			
11							**22,457**	**23,000**
32. 1					**75,000**			
2					75,000	**76,000**		
3		**75,000**						
4		**75,000**						
5				**77,000**				
6			**47,001**					
7	**47,506**							
8				**47,500**				
10					**25,000**			
11							**23,987**	**23,000**
33. 1					**78,000**			
2					**78,000**	**76,000**		
3		**80,000**						
4		**80,000**						
5				**77,000**				
6			**47,001**					
7	**47,506**							
8				**47,500**				
10					**25,000**			
11							**23,987**	
34. 1					**78,000**			
2					**78,000**			
3		**80,000**						
4		**80,000**						
5				**79,000**				
6			**47,001**					
7	**47,506**							
8				**47,500**				
10					**25,000**			
11						**25,000**	**23,987**	**25,750**
35. 1					**78,000**			
2					**78,000**			
3		**80,000**						
4		**80,000**						

Firm ID	BellS 1006	McCaw 5398	AirTch 7561	Mtel 7884	PageNet 9065	PMart 9683	AmerP 5403	Dubis 1942
5				**79,000**				
6			**47,001**					
7	**47,506**							
8				**47,500**				
10					**28,000**	**26,000**		
11							**26,875**	25,750
36. 1					**78,000**	**79,000**		
2					**78,000**			
3		**80,000**						
4		**80,000**						
5				**79,000**				
6			**47,001**					
7	**47,506**							
8				**47,500**				
10					28,000			**29,000**
11							**26,875**	
37. 1					**80,000**	**79,000**		
2					**80,000**			
3		**80,000**						
4		**80,000**						
5				**80,000**				
6			**47,001**					
7	**47,506**							
8				**47,500**				
10								**29,000**
11					**29,000**		**26,875**	
38. 1					**80,000**			
2					**80,000**			
3		**80,000**						
4		**80,000**						
5				**80,000**				
6			**47,001**					
7	**47,506**							
8				**47,500**				
10						**31,000**		**30,574**
11					**29,000**		**30,377**	
39. 1					**80,000**			
2					**80,000**			
3		**80,000**						
4		**80,000**						
5				**80,000**				
6			**47,001**					
7	**47,506**							
8				**47,500**				
10						**31,000**		
11					**35,000**		**30,377**	

TABLE VIIIG.

BIDDING HISTORY—ROUNDS 40–47 (ALL AMOUNTS IN $K; HIGH BIDS IN BOLD)

Firm ID	BellS 1006	McCaw 5398	AirTch 7561	Mtel 7884	PageNet 9065	PMart 9683	AmerP 5403	Dubis 1942
40. 1					**80,000**			
2					**80,000**			
3		**80,000**						
4		**80,000**						
5				**80,000**				
6			**47,001**					
7	**47,506**							
8				**47,500**				
10						31,000	**32,554**	
11					**35,000**			
41. 1					**80,000**			
2					**80,000**			
3		**80,000**						
4		**80,000**						
5				**80,000**				
6			**47,001**					
7	**47,506**							
8				**47,500**				
10						34,500	32,554	
11					**35,000**			
42. 1					**80,000**			
2					**80,000**			
3		**80,000**						
4		**80,000**						
5				**80,000**				
6			**47,001**					
7	**47,506**							
8				**47,500**				
10						34,500	35,726	
11					**35,000**			
43. 1					**80,000**			
2					**80,000**			
3		**80,000**						
4		**80,000**						
5				**80,000**				
6			**47,001**					
7	**47,506**							
8				**47,500**				
10						36,500	35,726	
11					**35,000**			

Firm ID	BellS 1006	McCaw 5398	AirTch 7561	Mtel 7884	PageNet 9065	PMart 9683	AmerP 5403	Dubis 1942
44. 1					**80,000**			
2					**80,000**			
3		**80,000**						
4		**80,000**						
5				**80,000**				
6			**47,001**					
7	**47,506**							
8				**47,500**				
10						**36,500**		
11					35,000		**35,726**	
45. 1					**80,000**			
2					**80,000**			
3		**80,000**						
4		**80,000**						
5				**80,000**				
6			**47,001**					
7	**47,506**							
8				**47,500**				
10					**37,000**	36,500		
11							**35,726**	
46. 1					**80,000**			
2					**80,000**			
3		**80,000**						
4		**80,000**						
5				**80,000**				
6			**47,001**					
7	**47,506**							
8				**47,500**				
10					**37,000**			
11						**38,000**	35,726	
47. 1					**80,000**			
2					**80,000**			
3		**80,000**						
4		**80,000**						
5				**80,000**				
6			**47,001**					
7	**47,506**							
8				**47,500**				
10					**37,000**			
11						**38,000**		

placed a fake bid when the FCC announces that no new bids or proactive waivers have yet been made in the round (i.e., all bids before the announcement had to be fake).

In what follows, I comment on the bidding on a round by round basis. These comments summarize the major strategic events in the particular round of bidding. Perhaps the most interesting strategic issue is the frequent use of jump bids to signal a strong demand for particular licenses. Out of the 196 new high bids in the auction, 96 (49%) were jump bids that exceeded the minimum bid by more than a bid increment. Of these 96 jump bids, 22 (23%) were jump raises of one's *own* high bid. The theory of jump bidding is discussed in the next section.

Monday, July 25. The bidding began at 10 AM and ended about 6 PM. The rounds were one hour long with a ten minute withdrawal period. The FCC took about twenty minutes to display results and begin the next round; hence, there was about $1\frac{1}{2}$ hours between rounds.

Round 1. Much information was revealed in the first round of bidding. Only four firms were eligible to bid on all ten licenses: McCaw, Mtel, PageNet, and Mobile Media. Hence, after the first round of bidding, PageNet learns that 5398, 7884, and 1666 are McCaw, Mtel, and Mobile Media (the three other bidders that were eligible to bid on all ten). Bids by McCaw and PageMart are surprisingly high. PageNet, AirTouch and others adopt a "snake in the grass" strategy: bidding the minimum bid on the cheapest license. Four bidders that were eligible to bid (i.e., that had filed short-form applications and made upfront payments), did not bid in the opening round. Apparently, these firms were unable to secure financing between the time of the upfront payment and the beginning of the auction. The number of active bidders was down from 29 to 25, even before the bidding began.

Round 2. Eight of twenty-five bidders drop out after the first round. The number of active bidders falls to 17. Mtel, who bid the minimum increment on all 10 in the initial round, jumps by $5 million to $15 million on license 3, and bids just over the minimum increment on all of the 50/12.5s. PageNet continues hiding in the grass.

Round 3. McCaw stakes out licenses 3 and 4 for the first time. McCaw's large jump bid, at least $10 million above the prior high bid, signals a strong commitment to two 50/50 kHz licenses. PageNet becomes convinced that 5398 is McCaw based on its aggressive strategy for two 50/50s.

Round 4. Mtel seems more interested in the 50/12.5s.

Round 5. Despite the high prices no additional bidders drop out since the first round. Seventeen bidders remain active.

Round 6. In the last round on Monday, PageNet comes out of the grass with a large jump bid of $30 million on all five 50/50 kHz licenses. The bids reveal the fourth bidder eligible to bid on all ten licenses. It also signals a strong commitment to three 50/50 kHz licenses. 9065 is a bidder to be reckoned with.

Tuesday, July 26. There was no change in the time between rounds. The bidding began at 9 AM and ended about 6 PM.

Round 7. McCaw responds to PageNet's challenge with a $10 million dollar jump to $40 million on licenses 3 and 4. The battle for the 50/50s is now in full swing.

Round 8. PageNet comes back with $42 million on licenses 1, 2, and 3, signaling a desire for three adjacent 50/50 kHz licenses.

Round 9. McCaw refuses to move off licenses 3 and 4 with another $10 million jump to $50 million. Apparently McCaw is avoiding the designated entity license 5.

Round 10. PageNet accommodates McCaw's desire for licenses 3 and 4 by bidding on license 5 at $43 million.

Round 11. After round 10, the number of active bidders has fallen from 17 to 16. This is the first drop in the number of active bidders, since round 1. PageNet responds to being bumped off license 5 by moving down to a 50/12.5 kHz license (#6). PageMart tests PageNet's resolve for two 50/50s.

Round 12. PageNet responds to the PageMart challenge with an $8 million jump bid on licenses 1 and 2, matching McCaw's bid of $50 million. PageNet is not going to be bumped from licenses 1 and 2.[24] At least one bidder used "cheap talk" to signal to competitors. Mobile Media used the bidder number of one of its rivals (PageMart, 9683) as the last four digits of its bid of $45,509,683. Apparently Mobile Media was telling PageMart to stay out of the 50/12.5s. In prior rounds, PageMart had been bouncing among the 50/50s and 50/12.5s.

Round 13. Both McCaw and PageNet have successfully fought off challenges on licenses 1 to 4. The battle on the 50/50s appears to be over who will get license 5.

Round 14. The number of active bidders has fallen from 16 to 15. McCaw is weakly challenged on license 3 by PageMart.

24. The next morning, the *New York Times* reported that this aggressive bidder (PageNet) was speculated to be BellSouth. "Gamesmanship and psychological warfare have been in full evidence. BellSouth, McCaw and other big bidders planned their strategies from carefully guarded hotel rooms, each one filled with computers. One of the biggest bidders—suspected to be BellSouth—had hung back and placed almost no bids until the final round of bidding had closed on Monday. Then it abruptly bid $30 million for each of [five] different licenses, and bumped two of those bids to $50 million today." (*New York Times*, July 27, 1994, p. D1.) This speculation was obviously incorrect, since BellSouth was not eligible to bid on more than three licenses in any round.

Wednesday, July 27. The FCC extended the hours of bidding. Bidding began at 9 AM and concluded about 8 PM.

Round 15. Both McCaw and PageNet respond with strength, jumping the price to $60 million. PageNet correctly anticipates McCaw's response to the PageMart challenge and matches McCaw's bid. Both McCaw and PageNet signal a willingness to go much higher in jumps of $10 million.

Round 16. PageMart responds by matching the $60 million price on license 5. It is too little too late. 5017 anticipates PageMart's bid and tops $60 million.

Round 17. McCaw immediately jumps to $70 million, even though it has not been bumped off of licenses 3 and 4. PageMart tests both McCaw and PageNet with a bid of $63 million on 2 and 3.

Round 18. PageNet responds to the challenge by matching McCaw's bid of $70 million.

Round 19. PageMart, thinking the fight for the 50/50s might be over, places a weak jump bid of $69 million on license 5. This will end activity on the 50/50s for the next 6 rounds. Bidding activity is shifted to the three 50/12.5 kHz licenses.

Round 20. The number of active bidders has fallen to 13. Bidders are starting to drop out. Prices on the 50/12.5s and 50s are low relative to the 50/50s. At least eight bidders are competing for the three 50/12.5s. Prices on the 50/12.5s will surely go higher.

Round 21. Mobile Media lays claim to a 50/12.5 with a jump from $40 million to $44 million.

Round 22. In the last round on Wednesday, PageNet maintains its claim on a 50/12.5 with a jump to $45 million on license 6.

Thursday, July 28. Seeing the deadline approaching, the FCC extended the hours and shortened the time between rounds throughout the day. The bidding began at 9 AM and continued until about 10 PM. The FCC announced, "Beginning in round 24, the rounds will be 45 minutes long and the withdrawal period will be 5 minutes long." In round 26, the FCC announced, "Beginning in round 27, we plan to begin 30 minute rounds and the withdrawal period will be 5 minutes long." The pace increased again in round 36, with the announcement, "From round 36 forward, we plan to begin using 20 minute rounds and the withdrawal period will be 5 minutes long."

Round 23. Bidders avoid 9065 on license 6, raising the bids on 7 and 8 above $45 million.

Round 24. AirTouch tops PageNet's bid on license 6 with a jump to $47 million.

Round 25. PageNet acquiesces on the 50/12.5, shifting its bid to license 10, a 50 kHz unpaired license. The shift is strong with a jump of $5 million from $15 million to $20 million. PageNet wants three licenses.

Round 26. There are now only 10 active bidders and just 5 new bids in the prior round. Bidding activity has fallen significantly. The fight for the 50/12.5s appears to be over. Indeed, round 25 will turn out to be the last activity on the 50/12.5s.

Round 27. The fight shifts to the two 50 kHz licenses. Five firms are competing for the two licenses.

Round 28. Bidding activity drops to its lowest level with just two new bids. Only eight bidders remain active. The end appears in sight.

Round 29. PageMart challenges both McCaw and PageNet with a bid of $71 million on licenses 2 and 3. This is the first challenge to McCaw's and PageNet's lock on the 50/50s in 11 rounds.

Round 30. Both McCaw and PageNet respond with strong jump bids to $75 million. The jump is one-half of the prior $10 million jumps, reflecting the reduced bid activity.

Round 31. Mtel matches the McCaw and PageNet bids, with a jump to $75 million on license 5.

Round 32. Mtel, anticipating a challenge from PageMart, raises its own high bid on license 5 to $77 million. PageMart, however, decides instead to challenge PageNet with a bid of $76 million. The identity of AirTouch is confirmed when their fake bid is revealed by the FCC's "no new bid" announcement.

Round 33. PageNet responds with a jump to $78 million on both 1 and 2. There are now four bidders on the 50/50s: PageNet, McCaw, Mtel, and PageMart. One of the four bidders must reduce its demand by one for the bidding to stop on the 50/50s.

Round 34. PageMart moves down to the 50 unpaired licenses, signaling a willingness to get out of the 50/50s. However, its bid on license 11 is topped by a bid by Dubis.

Round 35. With bids over $25 million on license 11, PageNet feels vulnerable and so raises its own high bid from $25 million to $28 million on license 10. This bid blocks PageMart's attempt to get in on the 50s with a bid of $26 million.

Round 36. PageMart responds by renewing its challenge to PageNet on the 50/50s with a bid of $79 million on license 1.

Round 37. Both PageNet and Mtel immediately respond to this renewed activity on the 50/50s by matching McCaw's bid of $80 million. This will prove to be the last bid activity on the 50/50s.

Round 38. There are now four firms competing for the two 50 kHz unpaired licenses: PageNet, PageMart, American Paging, and Dubis. PageMart makes a strong jump to $31 million, signaling an intention to come away with one license.